Phase 4: Project Analysis

Preliminary Project Report

Total Maximum Daily Load for Sediment in Aptos Creek and Valencia Creek, Santa Cruz County, California

September 2004

Regional Water Quality Control Board
Central Coast Region

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1. PROJECT DEFINITION

1.1. Introduction

The Aptos Creek Watershed is located in southern Santa Cruz County and encompasses approximately 24.5 square miles. The Creek drains to the Aptos Creek Lagoon and ultimately to Monterey Bay south of Santa Cruz, California. Aptos Creek's main tributaries are Valencia Creek, Mangels Gulch, and Bridge Creek. Trout Gulch is tributary to Valencia Creek (Figure 1-1).

Aptos Creek and Valencia Creek are listed for non-attainment of established water quality standards pertaining to sediment. Section 303(d) of the Clean Water Act requires the State to establish the Total Maximum Daily Load (TMDL) for sediment at a level sufficient to attain the water quality standard for sediment. The State must also incorporate into the TMDL seasonal variations and a margin of safety that takes into account any lack of knowledge concerning the relationship between load limits and water quality.

Aptos Creek, Valencia Creek and their tributaries historically supported healthy runs of both steelhead trout and coho salmon. However, due to increased sedimentation and other factors, the streams have experienced a reduction in the quality and amount of instream habitat capable of fully supporting the beneficial use of this cold-water fishery. This has contributed to the elimination of stocks of coho salmon and a substantial decline in stocks of steelhead trout. The acceleration of sediment delivery in the Aptos Creek watershed due to land management activities (historic and current) has contributed to the loss or reduction of pools necessary for salmonid rearing and the loss or degradation of potential spawning areas. In addition, the loss or reduction of instream channel structure in the watershed due to land management activities has contributed to this habitat degradation.

TMDLs and a Stream's Assimilative Capacity for Sediment

Sedimentation effects derive from the supply, transport, and distribution of sediment within a stream system. The supply can be traced to the various erosional processes that contribute sediment, including: landsliding, slumping, rilling, debris flows and bank failures. The quantity, timing and grain size of sediment delivered to the stream channel varies among these processes, as does their ultimate effect on fish habitat. These processes also have their genesis in both human (anthropogenic) and natural disturbances (SH&G, 2003, p. 4).

Once sediment is supplied to the stream, its transport and distribution are a function of channel geometry and hydraulic power. Human-induced changes to stream valleys, including the removal of trees or the construction of roads, can have a significant impact on channel function, especially when these changes occur within the inner gorge of the stream valley. Virtually any manipulation of the channel or of its stream flow that reduces hydraulic complexity will affect sediment distribution by limiting the sorting of fine sediment from coarser sediment. This in turn can eliminate or limit the creation of substrate features important to fish, such as pools, riffles and spawning gravels. Narrowing of the active channel by encroachment of land uses results in downcutting of the channel (incising), accelerated stream bank erosion, and entrainment of floodplain sediments that end up being deposited in the lower reaches of the watershed where the hydraulic forces (lessened by lower gradients) are insufficient to transport delivered sediment (Ibid.).

So, while the effects of sedimentation on beneficial uses are a function of the supply, or load, of sediment delivered to the stream, these effects also derive from factors controlling the transport and distribution of that sediment after its delivery. These factors combine to determine the stream's assimilative capacity for

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sediment. The Total Maximum Daily Load—more conveniently expressed as a maximum annual load—is that amount of sediment that can be delivered to the stream without exceeding its assimilative capacity. This document estimates the annual load that we would expect to be within Aptos and Valencia Creeks' current assimilative capacities. However, factors other than sediment supply (i.e., those controlling transport and distribution) will change over time, affecting these assimilative capacities. Management activities directed at these factors may result in increased assimilative capacity for sediment and should be pursued in concert with activities directed at reducing sediment supply.

1.2. Listing Basis

The Regional Board listed Aptos and Valencia Creeks on the 1998 303(d) impaired waters list based on sediment conditions characterized by the California Department of Fish and Game. Fish and Game staff conducted stream inventories of Aptos Creek, Bridge Creek, and Valencia Creek in the summer of 1997, which indicated sediment impacts to fish habitat (DFG, 1997).

1.3. Water Quality Objectives

The Central Coast Region's Water Quality Control Plan (Basin Plan) contains specific water quality objectives that apply wholly, or in part, to sediment (CCRWQCB, 1994, pg. III-3). These include:

Settleable solids: Waters shall not contain settleable material in concentrations that result in deposition of material that causes nuisance or adversely affects beneficial uses.

Sediment: The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.

Turbidity: Waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses.

Increase in turbidity attributable to controllable water quality factors shall not exceed the following limits:

1. Where natural turbidity is between 0 and 50 Jackson Turbidity Units (JTU), increases shall not exceed 20 percent.
2. Where natural turbidity is between 50 and 100 JTU, increases shall not exceed 10 JTU. Where natural turbidity is greater than 100 JTU, increases shall not exceed 10 percent.
3. Allowable zones of dilution within which higher concentrations will be tolerated will be defined for each discharge in discharge permits.

1.4. Beneficial Uses

The designated beneficial uses for Aptos Creek and Valencia Creek, as well as for their tributaries identified in the Basin Plan, are shown in Table 1-1. Only Aptos and Valencia Creeks (in bold) are listed as impaired for sediment. Mangels Gulch, a small tributary to lower Aptos Creek, is not identified in the Basin Plan. However, surface water bodies within Region 3 that do not have beneficial uses explicitly designated for them are assigned designations for municipal and domestic water supply, and protection of both recreation and aquatic life (CCRWQCB, 1994, p. II-1)

Table 1-1 Basin-Plan designated Beneficial Uses for waterbodies in the Aptos Creek Watershed

Waterbody Names	MUN	AGR	IND	GWR	REC1	REC2	WILD	COLD	MIGR	SPWN	BIOL	EST	FRESH	COMM
Aptos Creek	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Bridge Creek	x	x			x	x	x	x	x	x	x			x
Valencia Creek	x			x	x	x	x	x	x	x				x
Trout Gulch	x			x	x	x	x	x						x

Those beneficial uses most directly impacted by excessive sediment and/or turbidity include:

1. Cold Fresh Water Habitat (COLD) - Uses of water that support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish or wildlife, including invertebrates.

2. Migration of Aquatic Organisms (MIGR) - Uses of water that support habitats necessary for migration or other temporary activities by aquatic organisms, such as anadromous fish.

3. Spawning, Reproduction, and/or Early Development (SPWN) - Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish.

4. Municipal and Domestic Supply (MUN) - Uses of water for community, military, or individual water supply systems including, but not limited to, drinking water supply. According to State Board Resolution No. 88-63, "Sources of Drinking Water Policy" all surface waters are considered suitable, or potentially suitable, for municipal or domestic water supply except where:
   a. TDS exceeds 3000 mg/l (5000 uS/cm electrical conductivity);
   b. Contamination exists, that cannot reasonably be treated for domestic use;
   c. The source is not sufficient to supply an average sustained yield of 200 gallons per day;
   d. The water is in collection or treatment systems of municipal or industrial wastewaters, process waters, mining wastewaters, or storm water runoff; and
   e. The water is in systems for conveying or holding agricultural drainage waters.

1.5. Potential Effects of Excessive Sediment on Beneficial Uses

Fisheries (COLD, MIGR, SPWN)

Aptos Creek and Valencia Creek exceed narrative water quality objectives for settleable materials because beneficial uses have been adversely impacted by sediment deposition. The affected beneficial uses are those associated with cold water fisheries, specifically the habitat of anadromous fish: spawning gravels, pools and riffles. Steelhead/rainbow trout (*Oncorhynchus mykiss*) is present in the watershed and coho (*Oncorhynchus kisutch*) occurred historically. Both are members of the taxonomic family *Salmonidae*, which includes all species of salmon and trout, and with the exception of the resident rainbow trout, are anadromous—meaning they spend a portion of their life cycle in ocean waters before returning to spawn in the stream of their origin.

Fine Sediment in Spawning Gravels and Riffles

Fine sediment in spawning gravels has several effects on fish survival, including: 1) cementing the gravels in place and reducing their viability as spawning substrate, 2) reducing the oxygen available to fish embryos, 3) reducing intragravel water velocities and the delivery of nutrients to and waste material from the interior of the redd (salmon nest), 4) and impairing the ability of young salmon to emerge as free-swimming fish (Kondolf, 2000, p. 265, 266). These effects relate to the SPWN beneficial use and the potential for settleable material to affect spawning redds.

Riffles are a source of food for fish since they harbor benthic invertebrates (aquatic insects that live on the river/stream bottom) on which the fish feed. Data suggest that aquatic invertebrates are at least as sensitive to high levels of suspended sediment as salmonid fishes. Sediment can reduce or eliminate habitat for grazing benthic invertebrates that feed on periphyton by partially or completely covering riffles. Also, high suspended sediment levels tend to clog feeding structures, reduce feeding efficiency, and therefore reduce growth rates or stress or kill filter feeder invertebrates (Newcombe and MacDonald, 1991, p. 73).

Lack of Suitable Pools for Rearing Habitat

Pools in Aptos and Valencia Creeks, potentially suitable as rearing habitat, are impacted by fine and coarse sediment. Sedimentation in pools 1) reduces the volume of available rearing habitat by filling in pools and burying pool-forming structural elements such as large woody debris, 2) reduces pool depth and therefore the cool water refuge associated with temperature stratification, 3) reduces the availability of fish cover as a result of decreased depths and the burial of large woody debris and other structural elements, and 4) causes loss of surface flow as pools are filled in, resulting in less available habitat and protection from predators. These potential effects relate to the SPWN and COLD beneficial uses and the potential for settleable material (sediment) to impact rearing habitat.

Channel Aggradation and Stream Channel Instability

In addition to these primary effects on salmonids and their habitat, several secondary effects on the habitat of other species can occur. Channel aggradation is the increase in channel bed elevation resulting from the accumulation of sediment. While streams naturally have both aggradational reaches and degradational reaches, excessive channel aggradation can result from either an over supply of sediment or a reduction in the stream’s transport capacity. Whatever the cause of excessive aggradation, it results in the burial of large woody debris and other structural elements, the loss of a stream's ability to effectively sort gravel, and a potential reduction in the dominant particle sizes of sediment. Absent the structural elements that provide complexity and roughness to the channel, accumulated sediments tend to be mobilized under lower velocity, more frequent stream flows. These effects relate to the COLD beneficial uses and the potential for sediment to impact stream channel stability and habitat niches.

Elevated Turbidity and Suspended Sediment

Elevated turbidity and suspended sediment can result in decreased light penetration through the water column, impacting aquatic plants and the organisms dependent on them. Potential effects on fish swimming directly in water, in which solids are suspended, include: alarm reaction, increased morbidity (reduced resistance to disease, abrasion of gill tissue) and increased mortality. Turbidity can also affect the efficiency of methods for catching prey, reducing the catch per unit effort (Newcombe, 1997, p. 6). It is possible to relate severity of ill effect to the concentration of suspended sediment and the duration of exposure in all life stages of salmonids, freshwater invertebrates, and freshwater flora (ibid. p. 8). However, in Aptos Creek and its tributaries, neither data describing these effects, nor general observations of excessively long duration turbidity events are available.

Municipal Water Supply (MUN)

Sediment impacts to municipal water supply are not known to occur at this time in Aptos Creek or Valencia Creek, since groundwater is the only current known source of domestic water supply. However, turbidity could compromise any future development of creek waters for MUN beneficial use. Available data do not allow for a complete assessment of turbidity impacts to the watershed's streams, but grab samples from 1999 and 2000 showed turbidity that was higher and of longer duration in Valencia Creek relative to Aptos Creek (Coastal Watershed Council, 2000).

1.6. Statement of Impairment

The narrative water quality objective for settleable solids is exceeded in Aptos and Valencia Creeks and in certain tributaries to these creeks. Staff has reviewed no specific information or data providing evidence that the numeric turbidity objective or the narrative suspended sediment objective are exceeded in these waterbodies. Settleable solids in Aptos and Valencia Creeks impair beneficial uses supporting aquatic life, including COLD, MIGR, and SPWN.

2. WATERSHED DESCRIPTION

The major subwatersheds of the Aptos Creek Watershed include Aptos Creek, Bridge Creek, Trout Gulch, Valencia Creek and Mangels Gulch (Figure 1-1). The confluence of Aptos Creek and Valencia Creek is located immediately upstream of the Highway 1 Bridge, about one-half mile from the mouth of the Aptos Creek Watershed at Monterey Bay. While Aptos and Valencia subwatersheds exist side-by-side, have similar tributary lengths, and are of comparable size, they exhibit stark differences in the quality of their stream environments. Much of the following watershed description will contrast these two subwatersheds to provide a clear context for the subsequent analysis of substrate conditions.

Throughout this report, the phrase “Aptos Creek Watershed” is used in reference to the greater watershed that includes all tributary subwatersheds. The phrase “Aptos Creek subwatershed” is used for the smaller watershed surrounding Aptos Creek.

2.1. Land Use

The Forest of Nisene Marks State Park includes over 40 miles of trails, picnic areas, a backpacker campground, and interpretive historic sites (CDPR, 2003, p. 5). A small commercial development mostly comprised of retail outlets, food service and some lodging is at the lower end and outside of the State Park. This area, known as Aptos Village, along with the lower portion of Valencia Creek subwatershed, and the residential/commercial area on either side of Aptos Creek’s lowest reach, are areas in the watershed that approach urban densities. The lower portion of the Aptos Creek subwatershed and the entire Mangels Gulch subwatershed are settled with scattered rural residences. Trout Gulch and upper eastern Valencia Creek subwatersheds are rural residential with open spaces and small agriculture operations throughout.

The largest single land use in the watershed is the Forest of Nisene Marks State Park, located in the Aptos and Bridge Creek subwatersheds. It comprises approximately 10,036 acres of mostly undeveloped, second growth redwood and mixed evergreen forest, chaparral, and grasslands. The presence of the State Park is the most important land use difference between the Aptos and Valencia subwatersheds. The percent of watershed area under impervious surfaces is another expression of how these subwatersheds differ (Table 2-1).

Table 2-1 Main tributary characteristics

Subwatershed	Main Tributary Length (Miles)	Maximum Elevation (Feet)	Area and (%) of Impervious Surface
Aptos/Bridge Creek	7.2	2,624	0.23 mi^2 (1.9%)
Mangels Gulch	2.0	860	0.04 mi^2 (0.5%)
Trout Gulch	4.0	979	0.12 mi^2 (5.3%)
Valencia Creek	7.3	1,928	0.72 mi^2 (7.7%)
Aptos Mainstem	20.5	2,624	1.1 mi^2 (4.5%)

Source: SH&G, 2002b, p. 10.

2.2. Topography

The Santa Cruz Mountains extend from Daly City on the San Francisco Peninsula 80 miles southeast to the Pajaro River. Ridges and canyons dominate the terrain of Aptos Creek Watershed down to the lower reach, which levels out approaching the coastline. The highest point, Santa Rosalia Mountain, is approximately 2,500 feet in elevation. The Santa Rosalia Mountain ridge forms the northwest boundary of the watershed.

2.3. Climate

The variable and steep topography of the watershed results in variable rainfall over relatively short distances. Cool, wet winters produce average rainfall of over 50 inches per year in the headwaters and 22 inches per year at sea level (SH&G, 2003b, p. 9). Coastal fog throughout much of the summer is an important component of the watershed climate, especially at elevations up to 1,000 feet. Summer temperatures near sea level range from 50 degrees Fahrenheit in the morning to 75 degrees Fahrenheit mid day. In headwater areas (above 1,500 feet in elevation), summer temperatures range from 40 degrees Fahrenheit in the morning to over 100 degrees Fahrenheit mid day (CDPR, 2003, p. 7). Occasional light freezes and frost occur in the upper reaches and canyons of the watershed throughout the winter.

2.4. Hydrology

Most of the streams draining the west side of the Santa Cruz Mountains flow through steep-walled canyons to Monterey Bay. These streams tend to exhibit "flashy" (rapidly rising and falling) winter flows in response to rain storms. As the dry season progresses and the soil dries out, seeps and springs continue to supply the streams with groundwater. Summer baseflow is principally composed of this groundwater emerging into the stream channel, rather than from surface runoff flowing to the channel (CDPR, 2003, p. 7).

Aptos and Valencia Creek subwatersheds are similar in many respects, but their hydrologic conditions differ significantly. These hydrologic differences are likely the result of different land uses and dominant stream channel substrates. Compared to Aptos Creek, larger amounts of impervious cover in the Valencia Creek subwatershed affect runoff routing efficiency to the stream during rains, and decrease infiltration rates, limiting natural infiltration of rain water and the recharge of shallow groundwater. Furthermore, Aptos Creek displays pool and riffle morphology, where water storage can occur in low flow periods, while Valencia Creek's channel is sandy, unconsolidated, and lacking in complexity throughout the majority of its length (SH&G, 2003b, p. 50).

Streamflow data for Aptos Creek was collected by USGS at gages above the confluence with Valencia Creek. For the period 1951 to 2004, the largest peak daily flow for this portion of the creek was 3,980 cubic feet per second (cfs) and occurred during the flood of January 1982 (SH&G, 2003b, p. 10). The annual average flow ranged from 1.04 cfs to 33.75 cfs (SH&G, 2003b, p. 15). Based on flow data collected in the winter of 2003, SH&G made a first order approximation of the relative proportion that Aptos and Valencia Creeks supply in a runoff event within the Aptos Creek Watershed. They estimate that 20-30% of the flow is from Valencia and the remaining 70-80% is from Aptos Creek (p. 24).

These surface water discharge estimates, based on stream gage data, are influenced by groundwater extraction in the watershed, which began in 1950s. In addition to wells supplying the Soquel Creek Water District, an estimated 1,300 unregulated private wells draw water from the Aptos/Soquel groundwater basin. Additionally, many riparian residents along Valencia Creek extract groundwater, though no quantities have been calculated. Together, these groundwater removals affect the duration of in-stream baseflows that anadromous fish require (SH&G, 2003b, p.19). Because groundwater extraction typically peaks in the summer low-flow season, its effect is likely intensified during this time of year. SH&G suggest that groundwater removal may have the greatest impact on the hydrology of Valencia Creek, since groundwater recharge is limited there by the impervious cover associated with the more developed landscape (p. 22).

Both winter storm flows and summer base flows are critical to fish during different parts of their life cycle. The quality of rearing habitat is greatly influenced by the amount of stream flow, which affects pool depth, riffle conditions, and escape cover. Streamflow interacts with substrate and geomorphologic conditions to produce markedly different conditions in Valencia Creek when compared to Aptos Creek.

> "…alternating pool and riffle sequences and general morphological complexity in the Aptos Creek tributary… provides aquatic habitat even during extremely low stream flow conditions. While migration may be difficult, surface water storage and pool habitat is contained in many locations throughout the lower reach of this tributary. In contrast, the homogenous sandy substrate and the enlarged stream channel characteristic of Valencia Creek results in the typical low flow conditions that extremely limit the aquatic habitat and ability of fish [to pass]. Flows on order of one or two cfs in Valencia Creek are braided across the entire width of the existing channel… and can result in water depths no greater than a couple of inches and extend for many hundred feet along the stream reach." (SH&G, p. 22)

2.5. Aptos Creek Watershed Fishery

Aptos Creek has long been recognized as an important steelhead spawning and nursery stream. However, stocks have declined markedly since the 1960s. On August 18, 1997, National Oceanic and Atmospheric Association Fisheries (NOAA Fisheries, formerly the National Marine Fisheries Service or NMFS) published a final rule listing the Central California Coast steelhead Evolutionary Significant Unit (ESU) as a threatened species under the Endangered Species Act. An ESU is a distinctive group of salmon identified by NOAA Fisheries. The Aptos Creek watershed is at the southern end of the Central California Coast ESU for steelhead.

Coho salmon have been documented historically as far south as the Pajaro River, and there are undocumented reports that they occurred as far south as the Santa Ynez River. But, coho runs began disappearing from most streams south of San Francisco Bay starting in the late 1960s, and were last reported in Aptos Creek in 1973 (Hagar, 2003, p. 1, citing Anderson, 1995). In October 1996, NOAA Fisheries listed the coho as threatened in its Central Coast ESU. This coho ESU extends only as far south as the San Lorenzo River, so Aptos and Valencia Creeks are not specifically included in this federal designation. However, the California Fish and Game Commission listed the coho as endangered south of San Francisco Bay, effective December 31, 1995, and the Department of Fish and Game identifies the Aptos Creek watershed as a target of coho recovery in their planning document, *Recovery Strategy for California Coho Salmon*, (DFG, 2003, p. 1-1).

2.6. Amphibians and Reptiles

In addition to the special status fish, other aquatic species occur within the watershed. The following notes on the occurrence of amphibians and reptiles are taken from the Forest of Nisene Marks State Park General Plan environmental document (2003) (Refer to that document for references cited):

- Santa Cruz long-toed salamanders (*Ambystoma macrodactylum*) occur in a few areas in Santa Cruz County south of the City of Santa Cruz. Ponds within the State Park provide suitable habitat and are in close proximity to the northern Santa Cruz metapopulation for this species.
- California red-legged frogs (*Rana aurora draytonii*) can be found in a variety of habitats, with the largest frog populations being found in areas where there are perennial, deep (>0.7m) water pools bordered by dense, shrubby riparian vegetation. Within the Park, the red-legged frog is reported to be "common along streams, marshy areas, and ponds" (Thomson, 1995).

- California Tiger salamanders (*Ambystoma tigrinum californiense*) inhabit pool and grassland habitats and are occasionally found along stream courses. White's Lagoon, Buzzards Lagoon, and Hinckley Basin provide suitable habitat for this species.
- Foothill yellow-legged frogs (*Rana boylii*) inhabit rocky streams in a variety of habitats (CDFG, 1999); cobble sized substrate is suitable for egg laying (CDFG, 2001). These frogs probably spend most of their time in or near streams, and are rarely encountered far from permanent water, even during the rainy season (CDFG, 1999). They prefer the more open, downstream areas of large creeks and rivers, where they sun themselves on rocks and gravel bars (Welsh, H.H., T.D. Roelofs, and C.A. Frissel, 2000). Foothill yellow-legged frogs have been observed in Aptos and Bridge Creeks (CDFG, 1997a, 1997b).
- Western pond turtles (*Clemmys marmorata*) are freshwater turtles, found in permanent or nearly permanent water along lakes, ponds, and streams, and associated with secure basking sites such as logs and rocks surrounded by water, as well as undercut banks that provide refuge from predators such as raccoons (Welsh, H.H., T.D. Roelofs, and C.A. Frissel, 2000); California Department of Fish and Game, 1999). Upland forest habitats are used both for nesting and for overwintering (Welsh, H.H., T.D. Roelofs, and C.A. Frissel, 2000). Suitable habitat for the western pond turtle is available in the Park's creeks and lagoons.

2.7. Geologic context

The Aptos Creek Watershed lies within the Coast Ranges geomorphic province, which stretches along the Pacific Ocean from Southern California to the Oregon border, and is characterized by discontinuous northwest-trending mountain ranges. A geologic province is an area that possesses similar bedrock, structure, history, and age. The principal rock type of the area is sedimentary, formed under shallow seas from erosion of the continental landmass. These deposits have been compressed and folded under tectonic forces that express themselves most apparently in the San Andreas Fault complex, which traverses the upper watershed.

The most prominently exposed sedimentary rock type is from the Purisima Formation, which underlies over 60 percent of total watershed area, and no less than 50 percent of any individual subwatershed (Table 2-2). This formation, deposited approximately two million years ago, is a thick yellowish-gray siltstone containing lenses of sandstone and tends to be less consolidated, easy to weather, and susceptible to landsliding, especially within stream canyons. In fact the majority of landslides associated with the 1906 San Francisco and 1989 Loma Prieta earthquakes occurred in areas overlaying the Purisima Formation (CDPR, 2003, p. 9).

Eolian (wind deposited) sand units as well as some fluvial sand, silt, clay, and gravel units underlie the east branch and lower portions of Valencia Creek. The principal units here are the Aromas Formation and the Eolian Lithofacies (Table 2-2). These younger (0-2 million years before present) Quaternery deposits possess highly variable degrees of consolidation. Another important unit here, colluvium, is an unconsolidated, heterogeneous deposit of moderately to poorly sorted silt, sand and gravel deposited by slope wash and mass movement from, in this case, surrounding eolian deposits. Together these units make the east branch and lower Valencia Creek a highly unstable portion of the entire watershed.

Table 2-2 Major geologic units underlying Aptos Creek Watershed

Geologic Unit	Entire Watershed	Aptos Creek	Mangels Gulch	Trout Gulch	Valencia Creek
Purisima Formation	62.5	69.2	91.6	82.2	51.0
San Lorenzo Formation	6.3	12.9	0.0	0.0	0.0
Eolian Lithofacies	5.7	0.0	0.0	0.0	14.8
Colluvium	5.5	0.0	0.0	0.0	14.3
Vaqueros Sandstone	4.2	8.6	0.0	0.0	0.0
Aromas Sand	3.7	0.0	0.0	7.1	7.9
Alluvial Deposits	2.5	1.3	8.4	8.5	1.8

Source: SH&G, 2003, p. 10.
Major units here defined as those underlying more than two percent of total watershed area.

A major structural feature within the Purisima Formation is the Glenwood Syncline, which is a concave upward fold in the earth caused by tectonic compression. The Glenwood Syncline is typical of the fold belts that have formed in this area. In the uppermost portion of the Aptos Creek subwatershed, older and more tightly folded rocks occur along with small inclusions of Zayante Sandstone. In general these older sedimentary rocks are better cemented sandstones and siltstones that are more consolidated and massive, and therefore more resistant to weathering and slope failure (CDPR, 2003, p. 9).

2.8. Past Disturbance

The Aptos Creek Watershed has experienced a remarkable history of disturbance in the span of 150 years. This disturbance, which has been of both natural and anthropogenic form, continues to exert strong influence on sediment conditions throughout the stream network. These disturbances occur within a naturally dynamic landscape, as evidenced by the tectonic activity and floods that have helped to shape the watershed. Each disturbance is followed by a period of recovery that permits the recolonization of stream habitats by aquatic organisms. Steelhead have apparently evolved and adapted to persist through a wide range of conditions effected by this cycle of disturbance and recovery, though at varying population densities. The rate, pattern, and distribution of disturbance events effect outcomes for the entire stream biota, but generally support the biota in the long term when disturbance is of natural origin.

Disturbance in the watershed is now of natural and anthropogenic (human-induced), origin. Past human disturbance has profoundly altered the hydrologic and geomorphic structures and processes in the watershed. Continuing human disturbance now appears to be limiting the rate of recovery. The contrast between the Aptos Creek subwatershed, most of which is under protection as Nisene Marks State Park, and the Valencia Creek subwatershed, is evidence of how rates of recovery can be affected by human disturbance. The extent to which we can affect the process of recovery is a basic uncertainty at the center of restoration efforts in the watershed—including those efforts pursuant to the implementation plan for this sediment TMDL.

A summary of past human activities and natural disturbances, including floods, earthquakes and fires, illustrates the dynamic context in which current sediment loads are being estimated as a basis for this TMDL. This summary, derived from the Forest of Nisene Marks State Park Preliminary General Plan Draft Environmental Impact Report (2003, CDPR, pp. 32-44), emphasizes the Aptos Creek drainage, but logging operations of comparable scale and duration also occurred in the Valencia Creek subwatershed.

Settlement and Resource Extraction

Timber was first extracted on a commercial scale in the mid-1800s and continued into the early 1920s. The following chronology tracks the major incursions into the Aptos Creek Watershed for both timber harvesting and settlement. Appendix C provides the chronology in greater detail.

Mid-1800s

- 1866: small lumber and firewood boom; by late 1867 over 4,000 cords of oak firewood waiting to be shipped out.
- Water-powered mill, built along Aptos Creek in 1866 immediately beneath the present-day steel bridge, could cut 4,000 board feet of lumber a day; creek was dammed at the narrow spot and the resulting lake used as a millpond.
- 1867 to 1878: mill operated.
- Agriculture and industry appearing in lower Aptos Canyon, while upper Aptos Canyon remained relatively quiet. A few operators logged smaller redwoods in the more accessible reaches, carrying their product to the Soquel drainage on horses and mules.
- 1860s and 1870s: upper Aptos known as a legendary trout fishing stream.

1883-1900

- 1883: Loma Prieta Lumber Company formed to cut and mill lumber; Loma Prieta Railroad built a spur railroad line up Aptos Canyon to move big logs to the mill and carry the finished lumber down to Aptos.
- By 1890 Chinese workers had laid seven and a half miles of standard gauge track and built eleven trestles.

> "This was no delicate narrow gauge operation with tight curves and steep grades; this was an audacious, arrogant, broad-shouldered assault on some of the most convoluted and complicated landscape in all of California. They didn't go around ridges, they went through them; they didn't follow the twists and turns of Aptos Creek, they straightened it out with trestles. And each winter Nature took back what she had so reluctantly surrendered the previous spring. Winter freshets tore out the line and landslides twisted the track so that each spring long sections of the railroad had to be rebuilt. In some places at the upper end of the rail line the railroad grades cut into the canyon walls have completely disappeared, and the only clues remaining of the incredible human effort are twisted pieces of railroad rail in the bottom of the creek." (p. 37)

- Logging camps (temporary clusters of makeshift single-wall cabins clustered around the sawmills) were common throughout the mountains, but the Loma Prieta operation resulted in an actual town with a store, saloon, school, and church.
- Loma Prieta Mill was at that time the largest lumber mill in the Santa Cruz Mountains, capable of turning out 70,000 board feet of lumber during a regular twelve hour day.
- A three hundred foot cribbed log dam was built across Aptos Creek just upstream of the mill and logs were rolled into the pond and maneuvered into position to be drawn into the mill.
- Monte Vista Mill, a second smaller mill, built one and a half miles above the town site; it cut logs brought down the steep-sided Aptos Canyon.
- 1888: the Monte Vista Mill was moved to its final location seven miles above town in Aptos Canyon where it operated until all the good timber in the canyon was cut in 1899.

> "The fallers began at the creek bed and then worked their way up the steep-sided canyons, cutting all of the larger, good grade redwood (known as saw logs) and Douglas fir trees. Smaller trees and those with large imperfections were skipped, and today the second-growth redwood forest on the canyon walls is punctuated here and there by gnarled old growth trees that survived the onslaught. The saw logs were peeled, cut into sections, and then maneuvered into ravines and gullies where they were chained together and dragged down to Aptos Creek by teams of oxen. If the mill was close by and downhill, the logs were skidded directly there, but if necessary, they were loaded aboard

flatcars and taken to the mill by rail. Gravity was the logger's greatest ally. And much like the water that formed the gullies and ravines that etched the canyon walls, the logs were pulled down the watercourses to the railroad at creek level.

"All of this cutting, skidding and hauling had a colossal impact on the land. Side canyon gullies were scraped clear, and the dirt, rocks and other debris rolled into the streams…were then carried down to the main stem of Aptos Creek. Sawdust from the mills was thrown directly into the creek, and in the winter, the thick dust that covered every part of the logging operation washed into the creek. There are no glowing accounts of fishing on Aptos Creek published in the local newspapers after 1883…"(p. 38).

- Once the main logging operation was finished in an area, independent contractors who specialized in making split products (pickets, posts, ties) entered the ravines and cut down some of the trees left behind by those cutting saw logs.
- Tanbark crews also moved into the forest and cut the tanoak down and peeled off the bark in four-foot lengths. These rolls of tanbark were then hauled out by mules and sold to local tanneries.
- Also, other specialists like hoop pole contractors entered the woods and cut the hazelnut trees and sold them to coopers who used them to make barrel hoops.
- Winter of 1898-1899 this logging operation closes.

1906
- San Francisco Earthquake triggers landslide that buries Loma Prieta Mill.

1910-1917
- 1910 the Molino Timber Company was incorporated: workers put over ten miles of thirty-inch narrow gauge rail atop China Ridge. They produced split stuff – shakes, ties, pickets, posts and grapestakes. They cut and split the trees in the upper Hinckley Basin [Soquel Creek Watershed] and then raised the split stuff up to the level of the railroad. There is almost no evidence remaining of their operation.

1917-1922
- 1917: Loma Prieta Lumber Company purchased a track on the west side of Bridge Creek with an estimated 15 million board feet of redwood, including a cluster of large trees, one measured at eighteen feet in diameter. The company then extended their broad gauge line with a narrow gauge up Bridge Creek and harvested the trees, eventually turning what had been called Big Tree Gulch into Big Stump Gulch.
- 1922: Four-decades of logging ends. In the lands cut in the 1880s, redwoods were re-sprouting, creating a second-growth forest, the beginning of today's forests.

Natural Disturbances

Landslides and Earthquakes

Landslides triggered by seismic activity, climatic conditions, and human disturbance contribute a tremendous quantity of sediment to streams, principally in the steep headwater portions of the Aptos Creek Watershed. Descriptions such as those that follow underscore the preeminence of mass wasting, or landslides, among the various processes making sediment available to streams in the watershed. The largest recorded landslide triggered by the San Francisco Earthquake of 1906 occurred in essentially the same geologic environment as Bridge Creek to the west in Hinckley Creek, which flows to Soquel Creek.

> With the first severe shock of the earthquake, a landslide of 500 feet in width extending up to the ridgetop, descended with "extraordinary speed", burying the Loma Prieta lumber mill under a mass of rock and trees of "about 100 feet in depth a the worst places and gradually diminishing at the edges to 25 feet." Nine men were buried instantly, while others, only several hundred feet away, were spared. "The mountainside where the land fell was swept bare of vegetation. Massive redwoods and pines were jammed on top of the mill in the gulch below…the landslide filled the water course. The stream was dammed and the water rose to a depth of sixty feet in the gulch. A pump was set to working and the water is now being used to wash away the earth from the machinery." Hundreds were involved in a massive digging effort in the following week, but only three bodies had been discovered by five days later.
>
> —Santa Cruz Evening Sentinel, 26 April 1906, as recorded in Weber and Nolan, 1989, p. 8.

A description of the quake's effects in Aptos Creek, while rather vague, suggest significant effects there as well:

> On the western slope of Skyland, several earth avalanches were caused by the shock; and great slides of a similar character occurred on both sides of Aptos Creek for 0.75 mile. …on the ridge between Bridge and Aptos Creeks…there are well defined fissures up to 18 inches in width…and a relative movement of the east side a few inches toward the south…Great slides on both sides of Aptos Creek have almost made a valley of the canyon for fully 0.75 mile. Following across the ridges and canyons, the discontinuous line of slides and sinks in upland marshy places marks the course of the fault-line down into the lowland.
>
> —Lawson, et al, 1908, pp. 389, 110, as recorded in Weber and Nolan, 1989. p. 10.

Fire

Major fires affecting significant portions of watersheds generally result in increased sediment loads in stream channels for a period following the fire. While fire has natural origins, in the contemporary managed landscape the occurrence and fate of most fires is determined by human activity. In many populated areas, humans are the source of most ignitions, have the greatest effect on fuel loads, and with rare exception, aggressively intervene to control and/or extinguish fires. Thus while once part of the "natural disturbance" regime, fire in recent history is perhaps more accurately described as a semi-natural disturbance.

It is probable that lightening strikes generated significant wildfires in the Aptos Creek Watershed prior to recorded history. Native Americans are known to have used fire to manipulate wildlife and plant communities as far back as a thousand years ago. And later, loggers used fire to clear the brush and slash from their activities. On occasion, their fires escaped, sweeping through canyons and across ridges. Nevertheless, actual records of the size, location, and frequency of these fires are unavailable, with the exception of a major fire that occurred in 1922. It began in Hinckley Gulch on September 10 and burned for seventeen days, reaching down into Bridge Creek and north into the East Branch of Soquel Creek. The fire is estimated to have burned over an estimated 7,000 acres, much of it previously cut over land that had sprouted a dense cover of brush (CDPR, 2003, p. 42).

The Floods of January 1982

An estimated fifteen inches of rain fell in the upper reaches of the Aptos Creek Watershed on January 3, 1982. Aptos Creek became "a snarling, raging brown monster, tearing out creek banks and hurling entire trees, roots intact into the stream. Many of those trees and logs eventually congregated in logjams all along the creek with the largest building up behind the Speckles Drive bridge near the creek's mouth. Bridge Creek rose over 15 feet above its bed, tearing out old buildings and leaving mud marks high on tree trunks that are still visible today. Footbridges were swept away, and when the water receded, the steeper canyon walls up in the Aptos Canyon had been swept clean of vegetation" (Ibid., pp. 48, 49).

On lower Valencia Creek the effects of the 1982 storm were dramatic. "Eyewitnesses reported severe damage to Valencia Creek that included complete unraveling of the banks of the lower stream channel and 2 to 5 feet of aggradation that consisted almost entirely of sand-sized material" (Smith, personal communication as reported in SH&G, 2003, p. 38).

Loma Prieta Earthquake 1989

In the late afternoon of October 17, 1989 the San Andreas fault ruptured in its first major earthquake since the great San Francisco earthquake of 1906. Centered along a remote segment of the fault in the southern Santa Cruz Mountains, the earthquake re-ruptured the southernmost portion of the 1906 fault break. The epicenter of the main shock lies within the Forest of Nisene Marks State Park (Weber and Nolan, 1989, p.1).

Researchers entered the field after the earthquake and mapped ground cracking and landslides near the epicenter in the State Park. They concluded that the earthquake triggered no large deep-seated landslides in the park and found the vast majority of the landslides triggered by the earthquake were relatively shallow debris and rock avalanches, slides and falls concentrated in narrow and steep, V-shaped inner gorges of Aptos Creek (Ibid, p. 14, 15). Contributions of landslides to the total sediment load in the watershed are discussed in detail in the Chapter 4: Source Analysis.

2.9. Contemporary Disturbance

The watersheds are in recovery from these past disturbances at the same time that contemporary disturbances play out. Aside from the continuing and unpredictable pattern of natural disturbances like earthquakes, landslides, and floods, anthropogenic disturbances persist on both chronic and acute levels. For example, residential and commercial development along with related infrastructure for transportation and services, continue to have significant environmental effects in lower elevation portions of the watershed. Regional transportation infrastructure, centered on the Highway 1 corridor, has also resulted in considerable hydromodification from associated drainage facilities and from the effects of impervious surfaces on storm flows. One such facility, known as Valencia Lagoon, is located on the southwest side of Highway 1 just north of Rob Roy Junction; it functions as a retention basin for stormwater conveyed under the highway from Freedom Boulevard Creek.

The California Department of Transportation (CalTrans) maintains the facility according to Best Management Practice guidelines for retention facilities. CalTrans clears vegetation (mostly cattails) at the inlet of the facility on an annual basis to maintain flow capacity. The lagoon functions as a flood-retention facility with some sediment trapping capacity. It discharges to the mainstem of Valencia Creek. Over time the lagoon has accumulated enough sediment that CalTrans is now preparing a plan to remove and dispose of the sediment (J. Oneal, personal communication, April 27, 2004).

Residences built along streams have an effect on sediment supply and on the assimilative capacity of streams. For example residential roads built along streams require continuous maintenance to prevent erosion and sedimentation from posing risks to the channel. Often the maintenance is deferred and channel modification results. Additionally, roof and landscape drains concentrate flows and are often conveyed directly to the channel without energy dissipaters. Agricultural enterprises adjacent to the riparian zone also potentially introduce fine sediment to the streams beyond background levels. Timber harvests continue to occur in the upper and mid watersheds of Valencia Creek. Recreational activities in the State Park are intensive in some locations along Aptos Creek. Trails crossing creeks, park users in the creeks building rock dams, and foot traffic along stream banks, are all increasing sediment loads in areas where steelhead rear and/or spawn.

3. DATA ANALYSIS

3.1. Introduction

Concepts Driving Data Analysis

Several concepts drive the analysis of existing data on fish habitat and sediment conditions in the Aptos Creek Watershed. These concepts are reviewed here to support the discussion on analysis of data about 1) habitat conditions in the stream channel, 2) fish presence, absence, or abundance, and 3) estimated quantities of sediment generated by various sources.

The concept of *natural variability* in sediment transport is central to the evaluation of data about sediment conditions in the stream channel. Related to this is the concept of the channel's *assimilative capacity* for sediment, and the fact that there is a general trend toward a dynamic equilibrium wherein sediment loading and assimilative capacity change relative to one another in a compensatory manner.

Another useful concept is that of *landscape stratification*. In this analysis a simple stratification is applied, identifying hillslopes, riparian, and channel environments where erosion and sediment transport occur. On hillslopes the processes of erosion and sedimentation are wide ranging and include: sheetwash, rilling, gullying, animal burrowing, trampling, treethrow, dry ravel, soil creep, landslides and rainsplash (Reid and Dunne, 1996, p.23). In riparian areas streambank erosion and vegetation interactions dominate the process of sediment delivery and transport, and in the channel, scouring, remobilization of sediment, debris flows, and fluvial transport occur.

Madej discusses the concept of *disturbance and response* (1999, p. 15) and provides a useful iteration of four major parts of channel change through time, consisting of:

1) A disturbance or perturbation to the system
2) The time it takes before the system responds (lag time),
3) The length of time for change to occur, and
4) The recovery time (or relaxation time) for the channel system to return to its pre-disturbance state (if it does return to a previous state).

Important characteristics of channel response to disturbance include: the type, magnitude and frequency of change, its spatial distribution, the timing, duration and persistence of change, and the range and sources of variability (Ibid.). These concepts are useful in framing the discussion of channel condition within relevant time and spatial scales. For example, the effect of a natural or anthropogenic disturbance may persist for different periods in different portions of a channel network, as when a flux of fine sediment entering a steep headwater channel is quickly transported downstream, only to persist in a lower-gradient reach where it may have a relatively large effect on aquatic ecosystems (Montgomery and MacDonald, 2002, p. 2).

A final concept to bear in mind in this analysis of sediment-oriented data is that salmonid health and abundance are affected by *factors other than sediment*. For example, stream flow and energetic factors (water temperature, food availability, competition) also regulate steelhead and coho success, in addition to sediment-affected physical habitat features (pool and riffle abundance and depth, escape cover, substrate). Ocean residence of these fish exposes them to climatic factors, predation, and commercial fishing as well.

Data and Information Evaluated

The data and information evaluated for development of this TMDL, included:

1) Data addressing habitat quality, and fish populations. The main sources of this information were two reports:

- History and Status of Steelhead in California Coastal Drainages South of San Francisco Bay, Manuscript as of September 27, 1994 (Titus et al, 1994), and
- Technical Memorandum: Aptos Creek Watershed Assessment and Enhancement Plan: Salmonid Habitat and Limiting Factors Assessment (Hagar Environmental Science, 2002).

Excerpts from the Titus report pertaining to the Aptos Creek Watershed appear in Appendix A. The Hagar Report (2002) presents the findings of habitat surveys and fish observations evaluated to identify key factors that potentially limit fish populations in the watershed. This report appears in Appendix B. Staff also relied on stream surveys from 1997 and 2000 from the California Department of Fish and Game.

2) Data addressing sediment sources and substrate conditions:
John Dvorsky, with Swanson Hydrology & Geomorphology, prepared the Geomorphology & Sediment Source Assessment Technical Memorandum for the Aptos Creek Watershed Assessment (March, 2003). This report provided major findings on channel and substrate condition and was the basis of the quantitative source analysis.

3) Data addressing hydrologic conditions:
The Hydrologic and Water Quality Analysis report developed for Aptos Creek Watershed Assessment was an important source of basic hydrologic information on the watershed. Additionally, Barry Hecht and Mark R. Woyshner's, 1984 report, Storm Hydrology and Definition of Sand-Hill Recharge Areas, Pajaro Basin, provided insight into channel response to urbanization in the watershed.

4) Other data considered: these included timber harvest plans approved for the ten-year period 1992-2002, and observations from field reconnaissance conducted by staff on the following dates:

Watershed and Stream Reconnaissance	
Aptos Creek	**Valencia Creek**
	September 13, 2000
March 28, 2001 May 5, 2001 May 21, 2001	March 28, 2001 April 24, 2001 May 22, 2001 July 11, 2001
	September 24, 2003
May 6, 2004	May 7, 2004

Subwatershed Delineation and Reach ID

Previous studies delineated subwatersheds and stream reaches to organize data collection and analysis. Stream reaches were delineated by SH&G based on Rosgen's (1994) stream channel classification, which divides and classifies a stream based on local stream and valley morphology, gradient, and sediment characteristics (2003, p. 21). Reaches were labeled with a letter representing the name of the stream, and a number indicating the sequence in which they occur going upstream (e.g., "A-1" is the first reach identified for Aptos Creek and is downstream of A-2) (Figure 2-1).

SH&G (2003) divided the Aptos Creek Watershed into subwatersheds defined by the confluence of tributary inputs and/or significant changes in rock type (a characteristic expected to play a significant role in sediment production). Standard GIS algorithms applied to USGS 30-meter digital elevation model data were used to derive the subwatershed boundaries (Ibid., p. 16). A total of 18 subwatersheds were delineated for the Aptos Creek Watershed (Figure 1-1). These were grouped into four larger subwatersheds for the purpose of presenting the results (Table 3-1). Subwatersheds 5, 15, 19, 20, and 22 are not included among the 18 subwatersheds because they are artifacts of the GIS algorithm used for delineation and do not represent land areas of any significance to the analysis.

Table 3-1 Subwatersheds of the Aptos Creek Watershed

Subwatershed Number	Stream Length[a] (miles)	Reach ID Number	Acres[b]
Aptos Creek			7,726
1	2.59	A6	
2	1.18	A6	
3	7.58	A5&6	
9	7.40	A2, A3, A4, A5	
21	1.06	A1	
Bridge Creek			
4	3.92	B1	
Trout Creek Gulch			1,490
10	6.01	T1	
Mangels Gulch			545
12	2.12	M1	
Valencia Creek			6,020
6	1.09	V3	
7	0.78	V3	
8	4.88	V3	
11	4.58	V2	
13	2.49	V1	
14	2.33	V2	
16	0.79	V1	
17	0.94	V1	
18	3.57	V1	
23	0.61	V1	

Source: Data spreadsheets provided by SH&G.
a. Includes all tributaries
b. Includes Aptos and Bridge Creek subwatersheds
See Figure 1-1 for subwatershed and reach locations

3.2. Findings from Data and Information on Fish Populations and Habitat Quality

Historic (pre-2001) Fish Abundance and Habitat Quality

California Department of Fish and Game (CDFG) stream surveys from 1934, 1960, 1965, and 1975 all support the determination that Aptos Creek was an important steelhead spawning and nursery stream during these periods (Hagar, p. 1). Heavy winter storms in 1982 produced considerable flood damage in the Santa Cruz Mountains and had a profound effect on fish habitat in Aptos and Valencia Creeks. Subsequent years have seen recovery to near pre-1982 conditions in Aptos Creek and only marginal improvements in Valencia Creek. Table 3-2 is a compilation of both quantitative and qualitative information on salmonid abundance and habitat conditions for the period 1909 to 2000.

Insert Figure 2-1

Table 3-2 Historic and recent status (1909—2000) of salmonid abundance and habitat in Aptos Creek Watershed

Year	Habitat and Population Status	Location	Source
	APTOS		
1909	Juvenile steelhead/rainbow trout present	Not Specified	Snyder, 1913 (1)
1934	Juvenile steelhead: present; Spawning grounds throughout stream; Natural propagation very good; Fishing pressure for steelhead heavy.	Not Specified	CDFG (1)
1941	Condition of the stream apparently similar to 1934, although; Young-of-the-year and older steelhead: low abundance in stream; absent in lagoon	Not Specified	CDFG (1)
1960	Spawning and rearing habitats; high quality; No migration barriers or diversions Juvenile steelhead densities in non-pool habitats: about 5–10 trout/30 m in the upper survey area to 40–65 trout/30 m in the lower stream; Juvenile steelhead densities in pools: about 10–20 trout/pool; Siltation below Bridge Creek believed to have reduced steelhead production capacity of the stream somewhat through loss of cover for rearing fish	Not Specified	CDFG (1)
1963	CDFG plants 10,000 Alsea stock coho reared in Shasta County	Not Specified	Evans, 1963 (2)
1965	Spawning gravels: intermittent reaches in nearly 9 km of the stream; Rearing habitat: high quality for 13 km (8 mi.); No barriers or diversions; Juvenile steelhead average density: about 3.3 trout/meter over entire stream (100/100 ft), except for a 0.8 km (0.5 mi.) reach with 4.6 trout/meter (140/100 ft); Estimated total abundance of young steelhead: over 43,000; All steelhead observed were young-of-the-year; Natural propagation: good.	Not Specified	CDFG (1)
1968	Adult steelhead run about 1,500 fish (estimation method not described)	Not Specified	CDFG (1)
1975	Substrate: 10% fine gravel 25% coarse gravel 35% fine rubble 25% coarse rubble	Not Specified	No citation (2)
1976	CDFG plants 1,000 juvenile steelhead from the Noyo River	Not Specified	CDFG (1)
1981	Abundance of smolt-sized trout: relatively high compared to other streams surveyed in 1981(see Table 3-3) Rearing capacity: good	Upstream of the second bridge	Harvey & Stanley Associates, 1982 (2)
	Rearing capacity: fair to below average	Downstream of the second bridge	Harvey & Stanley Associates, 1982 (2)
	Primary limiting factors: substrate, cover, and spawning areas	Not Specified	Harvey & Stanley Associates, 1982 (2)
	Average pool depth: 0.75—1.3 ft Pool substrate: 53—90% bedrock and sand Riffles/runs substrate: 25—68% bedrock and sand 30—65% gravel and cobble	Not Specified	CDFG (2)
1982	(Following severe storms of January 1982):	From the mouth to	L. Turner, CDFG,

Year	Habitat and Population Status	Location	Source
	Spawning and rearing habitat degraded by siltation from landslides; Landslides and logjams created full or partial barriers to fish migration; Fish food organisms: scarce; No juvenile steelhead observed; Pre-smolts, present in previous fall, apparently killed or displaced by high flow, or emigrated to ocean; **Entire 1982 year-class apparently eliminated by siltation of gravels where eggs were incubating.**	2.4 km above confluence with Bridge Creek	unpubl. memo, 1 June 1982 (1)
	Substrate: 80% sand and silt 1% gravel 15% boulders and rubble 4% bedrock	Not Specified	No citation (2)
1985	A logjam remaining from the 1982 flood created at least a partial barrier to upstream migration of adult steelhead; Suitable spawning areas were lacking below the barrier, but as one progressed upstream through the survey area, substrate particle size increased on average and the overall abundance of suitable spawning gravel increased; Pools and shelter for rearing juveniles present throughout survey area; Yearling steelhead abundant below the barrier in the lower stream, but few young-of-the-year present there; Trout present above the barrier, and their abundance generally increased toward the upstream area; Lengths ranged from about 2.5 to 20 cm; In uppermost 2.8 km of survey area, both young-of-the-year and yearling steelhead/rainbow trout were abundant. Pool depth: 50% of length surveyed with depths up to 5 ft Substrate: a mosaic of silty sand and ruble upstream of Highway 1	Within the lowermost 2.4 km of first 9 km surveyed	D. Marston, CDFG, unpubl. memos. , 12, 20, & 26 August 1985 (1), and No citation (2)
1996	1+ and older trout density in pools: 1.8—25.8 fish/100 ft.	Not Specified	CDFG (2)
1997	32.8% of pools had pool depths 3 ft or greater Embeddedness of pool tail-outs: (1 indicates high quality spawning site; 5 is not suitable for spawning) 8.4% = 2 22.3% = 3 12.3% = 4 57% = 5 (92.2% of these were unsuitable based on particle size being too small) Dominant substrate of pool tail-outs: 51.9% sand 36.1% gravel	Not Specified	Survey conducted 3—5, 8 June 1997. Undated memo, CDFG, pp. 5, 6
2000	349 steelhead captured in 36 pools (53—330 mm fork length). This is a small sub-sample of fish present.	Lower 7 miles	J. Nelson, CDFG memo, 26 June, 2000, p. 1
	BRIDGE CREEK		
1960	Spawning areas: fair to good; Rearing habitat: adequate; Juvenile steelhead: common, 5–15 cm long	Middle and lower	CDFG (1)
	Spawning areas: very poor; Juvenile steelhead: absent	Above waterfall barrier (2.5 km	CDFG (1)

Year	Habitat and Population Status	Location	Source
		above confluence with Aptos Creek)	
1982	Landslides, logjams, and falls rendered the stream unusable for steelhead; Restricted access due to barriers; Stream bottom composed primarily of rubble and silt; No fish observed in the creek	Not Specified	L. Turner, CDFG, unpubl. Memo, 1 June 1982 (1)
1985	Juvenile steelhead/rainbow: present	Up to Maple Falls	D. Marston, CDFG, unpubl. memos. , 12, 20, & 26 August 1985 (1)
	VALENCIA CREEK		
1981	Rearing capacity: good	Downstream from Valencia Road	Harvey & Stanley Associates, 1982 (2)
	Primary limiting factors: pool depth, substrate, and flow	Not Specified	Harvey & Stanley Associates, 1982 (2)
	Abundance of smolt-sized trout: relatively high compared to other streams surveyed in 1981(Table 3-3)	Near Valencia Road crossing	Harvey & Stanley Associates, 1982 (2)
	Smolt-sized steelhead density 4.9 ± 0.9 trout/m (mean ± SD) (above the county-wide average).	Not Specified (two sites)	Derived from Smith 1982b (1).
	Average pool depth: 0.45—0.6 ft Pool substrate: 70—85% bedrock and sand Riffles/runs substrate: 30—48% bedrock and sand 50—70% gravel and cobble	Not Specified	CDFG (2)
1997	Pool depth: 1.5% > 2 ft Embeddedness of pool tail-outs: (1 indicates high quality spawning site; 5 is not suitable for spawning) 4.5% = 1 16.7% = 2 10.6% = 3 68.2% = 5 all of these were unsuitable based on particle size being too small and were found downstream of blown out culvert) Dominant substrate of pool tail-outs: 66.7% sand 13.6% small cobble 13.6% gravel	Not Specified	Survey conducted 3-5 June 1997. Undated memo, CDFG, pp. 5, 6

(1) As cited in Titus, et al, 1994, pp. 39-42.
(2) As cited in Hagar, 2002, pp. 1, 2.

The status of the steelhead population in the Aptos Creek Watershed prior to the floods of 1982 can be compared to that of other streams throughout Santa Cruz County (Table 3-3). Compared to other streams surveyed that year, abundance was relatively high in Aptos Creek upstream of the second bridge, and in Valencia Creek near the Valencia Road crossing. Below the confluence with Valencia Creek, lower Aptos Creek had the lowest average number of smolt-sized fish per 100 feet. From these data we can deduce that even prior to the 1982 floods, conditions in lower Valencia Creek were unfavorable for steelhead.

Table 3-3 Rearing densities of smolt sized steelhead (1981) in Santa Cruz County streams

Santa Cruz Area Stream	Average Number of Smolt-Size Fish/100 feet
San Vicente	40.9
San Lorenzo River	29.8
Aptos (Nisene Marks, upstream of 2nd bridge)	**24.0**
Zayante	22.0
Carmel	21.8
Valencia (downstream of Valencia Road)	**17.0**
Browns	16.5
Corralitos	16.1
Valencia average	**15.0**
Baldwin	13.8
Valencia (up Flume Road 0.75 miles)	**13.0**
Newell	13.0
Shingle Mill Gulch	12.7
Bear	12.0
Fall	12.0
Soquel West Fork	11.3
Aptos (County Park above railroad crossing)	**11.0**
Boulder	10.5
Mill (San Lorenzo)	10.5
Aptos Average	**9.6**
Bean	9.5
Majors	9.4
Jamison	8.0
Hester	7.0
Laguna	7.0
Aptos (just above Valencia)	**6.0**
Aptos (Nisene Marks, upstream of steel bridge)	**6.0**
Bates	6.0
Liddell	6.0
Pescadero	6.0
Ramsey	6.0
Soquel East Fork	6.0
Kings	5.0
Liddell West Fork	5.0
Moore's Gulch	5.0
Gamecock	4.0
Hinkley	3.0
Liddell East Fork	3.0
Lockhart Gulch	3.0
Soquel	3.0
Carbonera	1.7
Aptos (below Valencia)	**1.0**

Source: Harvey and Stanley Associates, 1984 as cited in Hagar, 2002.

Current Conditions

The Hagar Environmental Science Technical Memorandum (Hagar Report) presents results of stream habitat assessments performed between late August and early October 2001. This report provides the most complete and recent information on the condition of fish habitat in the creeks and allows for a comparison to historic conditions described in the previous section. The following text quotes substantially from the Hagar Report emphasizing parts of that report that pertain to habitat conditions affected by sediment. The complete text of the Hagar Report, which addresses the full suite of factors affecting habitat, is included in Appendix B.

Habitat Assessment Results

Survey reaches were designated based on Rosgen's classification, and accounted for gradient, tributary inflow, stream channel type, natural barriers, and other available geomorphology data. Reaches were then adjusted during field surveys to reflect actual conditions in the channel (Figure 2-1). The assessment team surveyed 8.5 miles of Aptos Creek from the mouth upstream to a point southeast of Whites Lagoon. Bridge Creek was surveyed from its confluence with Aptos Creek to about 1.2 miles upstream. Approximately 5.2 miles in Valencia Creek was surveyed from the Aptos Creek confluence to about 1.7 miles upstream of Valencia Road in the upper watershed. Trout Creek Gulch was surveyed from its confluence with Valencia Creek to the road crossing 1.3 miles upstream. A short section of Mangels Gulch was also surveyed, but was found to be mostly dry (Hagar, p. 7).

Habitat dimensions and type influence the ability of a stream to support steelhead and coho populations. Principal habitat types include: pools, riffles, and flatwater. Hagar found considerable variability in conditions between subwatershed areas and between reaches within subwatersheds. Most of Valencia Creek and Trout Creek consisted of narrow, shallow channels with predominantly sand substrate and no pools. Valencia Creek had lower flow and a narrower wetted channel than Aptos and Bridge Creeks. Depth was less for all habitat types in Valencia and Trout Creeks than in Aptos and Bridge Creeks, even in the smaller, upper reaches of Aptos Creek. Reach A-1 is atypical of the other reaches on Aptos Creek in that approximately half its length includes the lagoon. The other half is highly influenced by Valencia Creek and consists primarily of wide, shallow glide type habitat dominated by sand substrate. Habitat conditions improved upstream of Valencia Creek as the amount of sand substrates decreased (Hagar, pp. 9, 10).

Pools provide habitat during the summer low flow period and during droughts. Deeper pools can provide habitat for adult resident trout, coho parr (young fish that have not migrated to the ocean), and second year steelhead parr. In small streams fish may inhabit pools with mean depths of 0.5 to 1.5 feet, but are generally found in greater densities in streams with more pools in the 1.5 to 2.5-foot range (Ibid.). Pool depth is affected by accumulated sediment to a great extent and conditions throughout the Aptos Creek Watershed reflect this (Table 3-4).

Hagar found close to 30 percent of pools in the middle reaches (2, 3, and 4, Figure 2-1) of Aptos Creek averaging over one foot, and a significant number with depths of three feet or more. In the upper watershed, including Bridge Creek, pools were less extensive and shallower. Only three pools were identified in Valencia Creek—all in reach 3. The two lower reaches of Valencia Creek and the lower reach of Aptos Creek downstream of Valencia Creek had no pools. Hagar found a single deep pool in Trout Creek (Table 3-4) (Ibid.).

The predominance of sand in the channel substrates throughout the watershed is apparent in these data on pools and is even more evident when viewed as a percentage of total habitat units (see Figure 8: Dominant substrate composition, in Appendix B). In lower Aptos and in Valencia Creek, all habitat units surveyed by Hagar had sand as the dominant substrate (Ibid., p. 12). He found that sand diminished the total area of spawning gravel in lower Aptos Creek and throughout Valencia Creek. He found 2.3 to 4.4 square feet of spawning area per 100 feet of stream in the middle reaches (2 to 5) of Aptos Creek, and zero to 0.1 sq. ft/100 ft. in lower Aptos Creek and throughout Valencia Creek. Hagar found no potential spawning sites in the entire reach of Trout Creek (Ibid., p. 13).

Where present, spawning gravels were affected to varying degrees by embeddedness, but no stream had a majority of habitat units more than 30% embedded by fine sediment. Pool tails—not all of which are potential spawning areas—had higher levels of embeddedness, including significant percentages greater than 50% embedded in Aptos (reach 2) and Bridge Creeks (Table 3-5). Perhaps the most significant finding however is that total spawning area in Valencia Creek is only a fraction of that observed in Aptos Creek (Table 3-5).

Hagar compared fish observations with embeddedness conditions to evaluate the possible correlation between young-of-year steelhead abundance and embeddedness percentages of 15% or less (Table 3-6). He found that, "…abundance of young-of-year steelhead was highest in Aptos Creek in reach 5 where the most extensive areas of low embeddedness (<15%) also occurred. Densities of young-of-year steelhead were also relatively high in reach 4 and reach 6 but were lowest in reaches 2 and 3 where embeddedness estimates were generally higher…Both young-of-year and older trout were observed in reaches 2 and 3 of Valencia Creek although abundance was relatively low…As in Aptos Creek, abundance of young-of-year steelhead in Valencia Creek was greatest in areas where spawning areas were observed and where embeddedness ratings were lowest. No trout were seen in Trout Creek and this corresponded to some of the highest levels of fine sediments observed." (Ibid., p. 19).

Table 3-4 Aptos Creek Watershed pool characteristics (2003)

	Aptos Creek						Bridge Creek	Valencia Creek			Trout Creek
	A-1	**A-2**	**A-3**	**A-4**	**A-5**	**A-6**	**B-1**	**V-1**	**V-2**	**V-3**	**T-1**
Reach Length (ft)	1,649	7,134	8,340	10,366	9,251	7,952	6,461	5,599	12,581	9,232	7,018
Estimated Flow (cfs)	nm	2.5	nm	2.5	1.3	1.0	1.0	0.5	0.5	0.5	0.1
Mean Width (ft)	28.8	12.6	14.7	12.8	10.5	8.3	7.8	6.8	6.3	6.9	3.6
Average Pool spacing (ft)	na	183	203	247	189	209	294	na	na	3,077	7,018
Mean Length of Pools (ft)	na	77	124	88	71	37	25	na	na	25	10
Number of Pools	0	39	41	42	49	38	22	0	0	3	1
% Pools by length	0%	42%	61%	36%	38%	18%	9%	0%	0%	1%	0
% Pools with mean depth >=1.5 ft	*	26%	29%	29%	2%	8%	0%	*	*	0%	+
% Pools with mean depth >= 2 ft	*	5%	2%	10%	0%	3%	0%	*	*	0%	+
% Pools with maximum depth >= 3 ft	*	29%	44%	40%	14%	11%	0%	*	*	0%	+

Notes: See Figure 2 for Reach ID.
cfs: cubic feet per second
nm: not measured
na: not applicable, habitat type did not occur in stream reach
* no pools present
+ only one pool identified in Trout Creek

Source: Hagar, 2003, Table 2.

Table 3-5 Substrate characteristics by reach (2003)

	Aptos Creek						Bridge Creek	Valencia Creek			Trout Creek
	A-1	A-2	A-3	A-4	A-5	A-6	B-1	V-1	V-2	V-3	T-1
Areas with Spawning Gravel Surveyed	0	13	9	21	16	13	2	0	4	2	0
Spawning Gravel Area (sq. ft)	0	260	252	455	213	138	23	0	14	7	0
Spawning Area (sq. ft.) per 100 feet	0.0	3.6	3.0	4.4	2.3	1.7	0.4	0	0.1	0.1	0
Average spawning site size (sq. ft)	0	20	28	22	13	11	12	0	3.5	3.5	0
Pool Tail Embeddedness (%)	**Number of Habitat Units**										
0-15%	na	8%	0%	14%	28%	41%	10%	na	na	100%	na
16-30%	na	41%	46%	30%	36%	27%	30%	na	na	100%	na
31-50%	na	30%	49%	47%	32%	19%	40%	na	na	na	na
> 50%	na	22%	5%	9%	4%	14%	20%	na	na	na	na
Number of Pools Surveyed	0	37	39	43	47	37	20	0	0	3	0
Spawning Gravel Embeddedness (%)	**Number of Habitat Units**										
0-15%	na	23%	11%	33%	75%	31%	100%	na	75%	50%	na
16-30%	na	69%	89%	52%	25%	46%	0%	na	25%	50%	na
31-50%	na	8%	0%	14%	0%	15%	0%	na	0%	0%	na
> 50%	na	0%	0%	0%	0%	8%	0%	na	0%	0%	na

na = no pools or no spawning areas occurring in stream reach

Source: Hagar, 2003, Table 8.

Table 3-6 Trout observed during habitat inventory by reach (2003)

	Aptos Creek						Bridge Creek	Valencia Creek			Trout Creek	Mangels Creek
	A-1	**A-2**	**A-3**	**A-4**	**A-5**	**A-6**	**B-1**	**V-1**	**V-2**	**V-3**	**T-1**	**M-1**
Trout 4 in. or less (TL)	0	31	58	609	1143	146	59	0	79	34	0	0
Trout over 4 in. (TL)	0	16	22	27	20	21	10	0	13	10	0	0
Sum of Habitat Length (feet)	1,649	7,134	8,340	10,366	9,251	7,952	6,461	5,559	12,581	9,232	7,018	1,452
Y-O-Y/100 ft (<4 in.)	0.00	0.43	0.70	5.87	12.36	1.84	0.91	0.00	0.63	0.37	0.00	0.00
Older trout/100 ft (>4 in.)	0.00	0.22	0.26	0.26	0.22	0.26	0.15	0.00	0.10	0.11	0.00	0.00
Spawning Area (square ft) / 100 ft	0.0	3.6	3.0	4.4	2.3	1.7	0.4	0	0.1	0.1	0	
% Units with pool tail embeddedness <= 15%	na	8%	0%	14%	28%	41%	10%	na	na		na	
% Spawning areas with embeddedness <= 15%	na	23%	11%	33%	75%	31%	100%	NA	75%	50%	na	

Notes:
TL: total length
Y-O-Y: young-of-year
na: not applicable

Source: Hagar, 2003, Table 12.

Potential Limiting Factors for Fisheries

Steelhead and coho populations are generally depressed along the Central California coast. Determining the specific factors that have brought this about is challenging given the natural variability in environmental conditions and the complexity of salmonid life history. Limiting factors affect productivity under natural conditions. The identification of a limiting factor does not assume anthropogenic alteration of that factor. Absent human disturbance, sediment can be the principal factor limiting habitat quality and quantity, and in turn, salmonid productivity. Other common factors that limit production of steelhead and salmon in coastal streams typically include:

- Migration obstacles that limit or preclude access to suitable habitat;
- Excessive stream temperature that eliminates rearing potential or truncates migration periods;
- Seasonal elimination of rearing or migration habitat through loss or reduction of stream flow during key periods;
- Reduction of rearing capacity due to lack of instream cover;
- Excessive mortality due to toxic water quality episodes (fuel spills, waste disposal, swimming pool/hot tub discharges, etc.);
- Diminished spawning success due to human disturbance;
- Reduction in spawning populations due to excessive legal or illegal harvest (Ibid., pp. 16, 17).

For the Aptos Creek Watershed, Hagar (2002) endeavored to deduce potentially limiting factors from his observation of key habitat features and the limited information he obtained on abundance and population structure. He concluded that:

> "Sediment is likely the major factor limiting salmonid production on both a watershed and individual reach scale…Fine sediments also likely diminish the productive capacity of Aptos and Bridge Creeks though not to the same degree as in Valencia Creek.
>
> "Evidence from past sampling indicates that Valencia Creek has had higher densities of rearing trout and lower levels of fine sediments than currently occur and that conditions changed relatively dramatically after sediment deposition during the high flow winter of 1982. Production of trout in Valencia may be reduced by an order of magnitude relative to Aptos Creek since surveys were last conducted in 1981.
>
> "Any increase in sediment loading in Aptos Creek has the potential to reduce steelhead productivity and, in the worst case, could induce a threshold response resulting in dramatic declines in the capacity of the watershed to support steelhead such as has apparently occurred in Valencia Creek." (p. 19).
>
> "Beyond limitations imposed by lack of a spawning population and ocean conditions, coho would likely be limited by many of the same factors limiting steelhead as discussed in the preceding section, particularly sediment." (p. 21).

Table 3-7 presents Hagar's summary of the potential primary and secondary limiting factors for steelhead in the Aptos Creek Watershed (Appendix B presents a detailed discussion of all of these factors). These findings indicate where sediment management may play the most critical role in improving the viability of salmonid populations in the watershed. However, they do not indicate the degree to which human disturbance effects these conditions. For example there is virtually no remaining human disturbance in the Bridge Creek subwatershed, yet sediment is the primary limiting factor there. In combination with findings presented elsewhere in this report concerning levels of human disturbance, Hagar's summary of limiting factors are a useful guide for prioritizing sediment management activities consistent with the implementation plan for achieving the sediment TMDL discussed later in this report.

Table 3-7 Summary of limiting factors for steelhead productivity.

Stream Reach	ID	Primary Limiting Factor	Secondary Limiting Factors
Aptos Creek	A-1	Sediment	Rearing cover
	A-2	Sediment	Rearing cover
	A-3	Sediment	Rearing cover
	A-4	Sediment	Rearing cover
	A-5	Sediment	Rearing cover
	A-6	Adult migration access	Sediment
Mangels Gulch	M-1	Lack of summer flow	–
Bridge Creek	B-1	Sediment	Adult migration access
Valencia Creek	V-1	Sediment	Adult migration access
	V-2	Adult migration access	Sediment
	V-3	Adult migration access	Sediment, low stream flow
Trout Creek	T-1	Sediment	Adult migration access, low stream flow

Source: Hagar, 2002, Table 11.

3.3. Findings from Sediment Data

Channel Conditions

Approach and Methods

SH&G combined field work and hydrologic modeling to quantify some of the factors affecting channel condition and improve understanding of how these factors interact to potentially control observed habitat conditions. They examined grain size of channel sediment, channel morphology, and aspects of stream flow.

Selecting sites that were accessible and representative of the reach as a whole, SH&G surveyed stream cross-sections on all of the reaches designated for the watershed assessment. They surveyed three cross-sections—from 100 to 200 feet apart—at each site to obtain accurate estimates of the thalweg, water surface, and bankfull slope of the channel.

At each group of three cross-sections, the survey teams conducted one pebble count on the depositional features within the low flow channel to estimate whether sediment of the size found there would be mobilized during different flow events (see Appendix D, Figure 9: Sediment Sample and Cross-section Survey Locations). Sheer stress is the hydraulic variable used to determine the size of material that a stream can move and hold in suspension during a discharge event. SH&G calculated dimensionless sheer stress for each site for a range of discharges using the output of a HEC-RAS hydraulics model[1]. By loading the cross-section data into the model, water depth and surface slope at each site, for each discharge event was generated, and from these SH&G calculated the dimensionless sheer stress. They then developed a curve for each site comparing the expected minimum diameter grain-size that would be mobilized in a given discharge event (SH&G, 2003, pp. 30-31).

[1] The U.S. Army Corps of Engineers developed the Hydrologic Engineering Center's River Analysis System (HEC-RAS) model. HEC-RAS is an integrated package of hydraulic analysis programs, in which the user interacts with the system through the use of a Graphical User Interface (GUI). The system is capable of performing Steady and Unsteady Flow water surface profile calculations. Source: downloaded 3/30/04 from website: http://www.bossintl.com/online_help/hec-ras/source/workingwithhecrasanoverview4.htm.

Findings

The chief finding of the analysis of substrate conditions is that fine sediment is present throughout the watershed with the most degraded reaches being Aptos (below the confluence with Valencia), Trout Creek, Mangels Gulch, and Valencia Creek. In lower Aptos, Mangels, Trout and a few reaches of Valencia, the bed is mobile during even low to moderate flows (Table 3-8). As the SH&G report states: "A highly mobile bed, combined with a significant quantity of fine-grained sediment moving through the stream channel, precludes use of the stream channel for successful spawning. Even if spawning were to occur, rearing habitat appears to be limited" (Ibid., p. 45).

Table 3-8 Pebble count results from cross-sections in Aptos Creek Watershed, March 20-25, 2002.

Stream Reach	ID	D16 (mm)	D50 (mm)	D84 (mm)	Percent Fines (<2 mm)	Approximate flow required to move D50 (cfs)
Aptos Creek	A-1	1.0	1.0	1.0	98	3
	A-2	30.0	55.0	100.8	0	>200
	A-3	1.0	11.0	46.2	30	35
	A-4	1.0	34.5	77.1	29	175
	A-5	1.0	55.5	115.2	19	130
	A-6	1.0	25.0	58.0	17	5
Mangels Gulch	M-1	1.0	3.0	16.0	49	<1
Bridge Creek	B-1	1.0	22.0	62.3	26	40
Valencia Creek	V-1	1.0	10.0	40.2	39	10
	V-2	1.0	15.5	52.5	37	30
	V-3	1.0	9.5	40.3	39	3
Trout Creek	T-1	1.0	1.0	6.2	77	<1

Note: Values for D16, D50, and D84 represent the diameters of the 16th, 50th, and 84th cumulative percentile of particles, respectively. For example, a D50 of 55 mm means that 50 percent of the particles in the pebble count have an intermediate diameter of 55 mm or less.
These data represent late winter conditions with higher percentages of coarse material than would be found during summer months when much of the coarse material is covered by sand.
Results for A-2 may constitute an outlier associated with site selection.
Source: SH&G, 2003, p. 50, Table 10.

While SH&G's data sets are not directly comparable to those presented in the Hagar Report, (Hagar employed qualitative methods and confined his substrate analysis to pool tail-outs and potential spawning gravels) they support each other in identifying the distribution and type of substrate conditions in the watershed.

Sediment Output

Approach and Methods

SH&G endeavored to estimate the amount of sediment being transported through the streams of the Aptos Creek Watershed. To develop this estimate—termed "sediment output"—they used streamflow data and suspended sediment data. In addition to historic USGS gauging data, streamflow data were collected from temporary streamflow gages installed on Aptos and Valencia Creeks. Suspended sediment samples were collected at these same locations during peak flow events. Total Suspended Sediment Concentrations (SSC) were calculated from the sediment samples and a rating curve, relating SCC to discharge, was developed for one site on Aptos Creek at the County Park.

Equipped with this new rating curve, SH&G calculated a long-term sediment yield for the County Park site using USGS flow data from 1959 to 1985. Discharge for each day was multiplied by the SSC developed from the rating curve to estimate total daily suspended sediment yield. Daily values were then summed to get tons of sediment per year. Estimated annual loads from 1959 to 1985 were averaged to produce an average suspended sediment yield per year for the portion of the Aptos Creek Watershed upstream of the confluence with Valencia Creek.

Bedload data are not available for streams in the watershed, so SH&G assumed that bed load would be approximately 25 percent of suspended load. This estimate is higher than the ten percent figure commonly used in streams with bed material dominated by coarse substrate requiring high flows to mobilize significant amounts of material. The higher value was selected, since Aptos and Valencia Creeks are dominated by fine and coarse-grained sand mobilized during lower magnitude events (SH&G, 2003, pp. 28, 30).

Findings

Approximately 25,694 tons/year of sediment is transported through Aptos Creek at the County Park site upstream of the confluence with Valencia Creek (Table 3-9). This estimate of output is important for calibration of the source assessment results discussed in the following section. The rating curve developed to estimate suspended load is likely to underestimate the amount of sediment being moved during larger events, since SH&G's sampling was limited to fairly low magnitude events (Ibid., p. 39). Thus, SH&G concludes that the results may be an underestimate of actual average loading from this subwatershed. It is not uncommon for sediment budget calculations to have a significant margin of error given the inherent challenges in calculating these budgets and the need to make general assumptions about the processes affecting delivery and transport of sediment through the system (Reid and Dunne, 1996 as cited by SH&G, 2003, p. 39).

Table 3-9 Estimated suspended and bedload transport through Aptos Creek based on field measurements made by SH&G (2003) and historic streamflow records.

Water Year	Suspended Sediment Yield (tons/yr)	Suspended + Bedload (tons/yr)
1959	3,562	4,453
1960	1,525	1,906
1961	48	59
1962	5,708	7,135
1963	60,532	75,665
1964	862	1,078
1965	14,527	18,159
1966	146	182
1967	27,322	34,153
1968	2,041	2,551
1969	32,912	41,140
1970	27,357	34,196
1971	1,219	1,524
1972	109	137
1973	31,108	38,885
1974	11,980	14,975
1975	4,257	5,322
1976	56	70
1977	24	30
1978	17,724	22,155
1979	1,535	1,919
1980	35,904	44,879
1981	1,182	1,477
1982	199,907	249,884
1983	63,852	79,816
1984	7,955	9,943
1985	1,638	2,047
Average	**20,555**	**25,694**

Source: SH&G, 2003, p. 41, Table 8.

3.4. Findings from Previous Studies on Hydromodification

The transition of a watershed from a natural, forested state to a predominantly urban condition encompasses removal of vegetation and canopy, compaction of soils, creation of impervious surfaces, and alteration of natural drainage networks. These activities, all of which have occurred to varying degrees in portions of the Aptos Creek Watershed, result in increased surface runoff and changes to sediment budgets, and in turn induce a geomorphic response, commonly resulting in enlarged, unstable channels (Henshaw, 1999, p. 1). The combined effect of this transformation alters the hydrologic function of waterbodies.

Hydromodification is important to consider here, because it potentially limits the capacity of streams to assimilate a given sediment load. Focusing efforts on controlling sediment loads while failing to address the assimilative capacity of streams to which those loads are delivered may result in a Sisyphean struggle wherein reduction of loads to levels even below background does not substantially improve fish habitat.

A report from 1984 documents the hydromodification effects of urbanization on the Valencia Creek watershed and illustrates the degree to which these effects can mediate sediment production and transport.

Approach and Methods

Hecht and Woyshner conducted investigations into the effects of urbanization in Santa Cruz Mountain watersheds in 1984. They compared peak flows in several small watersheds and found differences at least partly attributed to the extent of urbanization and impervious cover. Their field studies were conducted over the wet winters of 1981-82 and 1982-83, water years 1982 and 1983, respectively. They installed crest-stage gages on small channels draining sandy areas, including four drainages in the Valencia Creek subwatershed. Most of these basins were paired, with one being at least partially urbanized and the other being almost entirely in agricultural or open-space uses (Hecht and Woyshner, 1984, p. E-3). The drainages in the Valencia Creek subwatersheds were centered on an east branch tributary they call "Freedom Boulevard Creek," which follows Freedom Boulevard to Rob Roy Junction at the Pacific Coast Highway.

Findings

The authors designed the 1984 study in part to characterize the effects of differences among the basins, including differences in size of drainage area and rainfall and the resulting effects, on the magnitude and duration of storm runoff. They also identified other influential factors, such as soil type, antecedent soil moisture, hillslope gradients, and valley slopes and channel development (Ibid., p. E-10). Among these, they found channel development to be of particular importance.

<u>Discharge</u>

Instantaneous peak discharges for most large storms were computed from field gages and then converted to peak runoff per unit drainage area (cfs/mi^2). Results indicated that peak unit runoff was substantially higher in channels draining small basins with significant amounts of urbanized area. Peak unit runoff increased sharply with the percentage of the basin covered by impervious surfaces (roofs, roads, drive-ways, parking areas, corrals, building pads at construction sites, and steep artificial embankments). Drainage characteristics and resulting discharge for the basins are presented in Table 3-10.

Table 3-10 Peak flows in Valencia Creek drainage basins (1982 and 1983 Water Years)

Drainage Basin Name	Channel Type	Drainage Area (acres)	Drainage Area (mi^2)	Impervious Area[a] (Percent)	Land Use	Jan. 1982 Peak Flow (cfs)	Jan. 1982 Unit Runoff (cfs/mi^2)
Wallace Avenue	Gutter	90	0.14	40	Suburban; estates (minor)	150	1,050
Aptos Orchards @ Aptos Assembly Church	Access road rut	50	0.08	0	Orchard; chaparral	6	76.5
Aptos High School @ Entrance	Culvert	161	0.25[b]	18	High School and chaparral	205	824
Moon Valley Creek	Incised, stable	146	0.23[b]	0	Agriculture	45	198
Freedom Blvd. Creek @ Aptos High Road	Unstable and rapidly incising[c]	1,130	2.55	18	Rural and suburban residential; open space, agricultural, institutional	310	122

Source: Hecht and Woyshner, 1984, Table 1, p. E-5, and Table 4, p. E-14.

a. Determined from point counts using 1979 aerial photograph, 1"=1000.'

b. Less than 10 percent but more than 1 percent of this basin affected by small agricultural impoundments.

c. Channel cross-sectional area increased 8- to 10-fold during January 1982 storm (see Figure 3-1).

Channel Development

Channel development is an ongoing process throughout the sandy soil areas in this region and is especially prevalent in areas underlain by the Aromas Formation (p. E-20). The Aromas Formation is a heterogeneous sequence of mainly eolian (wind deposited) and fluvial sand, silt, clay, and gravel. Within the Aptos Creek Watershed, this formation is only present in lower Valencia Creek and Trout Gulch subwatersheds, where it accounts for 474 acres (7.9 percent) and 106 acres (7.1 percent) of total subwatershed area, respectively (Table 2-2). Other dominant formations in the Freedom Blvd. Creek subwatershed, include moderately well sorted eolian sand with highly variable degrees of consolidation (approximately 35 percent of this subwatershed), and colluvium; an unconsolidated, heterogeneous deposit of moderately to poorly sorted silt, sand and gravel deposited by slope wash and mass movement from surrounding eolian deposits (approximately 34 percent of the subwatershed) (SH&G, 2003, pp. 8, 9). As with the Aromas Formation, these formations are also highly erodible and susceptible to channel development.

Hecht and Woyshner compared pairs of basins that differed primarily in their extent of channel development and runoff regime. Two small drainages, Aptos Orchards and Aptos High School (Table 3-10), located on opposite sides of Freedom Boulevard have very similar rainfall, slopes, and percentages of very sandy soils. They differ to a certain extent in drainage area, but more significantly in how their different land uses have affected drainage density.

> "Aptos High School is situated in the center of a bowl-shaped valley, whose developed portion is drained by numerous gutters and ditches into a single arterial culvert. By contrast, the main drainageway of the Aptos Orchards basin is a small and discontinuous rut in the overgrown service road, which meanders through the orchard. Overland flow from the steep slopes ringing the valley and from the orchard itself must travel several hundred feet across the relatively flat, sandy valley floor before reaching the embryonic channel system." (p. E-18)

In the larger watershed of Freedom Blvd. Creek, which encompasses these two smaller drainages, the authors found a large channel developed along the full length of the mainstem. They also found drainage ditches along Cox Road, along a tributary valley, paved and placed in culverts, and small channels developed in two left bank valleys where previously grassy swales had been. The result of these and other hydromodifications is that the drainage network of Freedom Blvd. Creek is now nearly completely integrated (connected). Integration of the drainage network allows runoff that was previously conveyed along grassy valley floors lacking defined channels to be conveyed more directly, at higher velocities, and with more erosive potential into the main channel causing incision and channel instability (Table 3-10).

Peak rates of runoff from basins with incised, well-developed or paved channels are much higher than those from basins that have retained their grassy drainageways (E-18). The 1984 study found most of these channels to be unstable, incising and extending headward, though some, like Moon Valley Creek just outside the watershed, were found to be stable (Table 3-10). The authors gave an example of channel incision from a site on Freedom Blvd. Creek, illustrating the typical channel growth rate during the two wet years of their study (Figure 3-1). The figure was made from field sketches drawn just before and after the January 1982 storm. It is apparent in this figure that large amounts of sediment were eroded from the bank and entrained in floodwaters in that event.

The 1984 study showed that hydromodification in the Freedom Blvd. tributary to Valencia Creek has been an important outcome of urbanization. This hydromodification has affected the sediment regime of Valencia Creek by integrating the watershed's drainage network, making peak flows higher and exerting greater erosive energy on the landscape over which they flow. Though other portions of the Aptos Creek Watershed affected by urbanization were not included in the 1984 study, we would expect these same effects to occur, though less pronounced outside of Valencia Creek's lower subwatersheds (14 and 18 in Figure 1-1), since the geology and soils of areas outside are relatively more stable.

The study also provides the only available explicit measure of channel erosion from the 1982 flood, albeit at only one location. It is consistent with anecdotal information about the effects of the flood on lower Valencia Creek. This measure also reinforces two important concepts driving this analysis—*natural variability* and *disturbance and response*. While infrequent, the occurrence of major storms like the one that occurred in 1982 follows no clear pattern and is characteristic of the natural variability of California's central coast drainages. The concept of disturbance and response is useful in framing the channel disturbance from floods in context with the recovery time (or relaxation time) for the channel system to return to its pre-disturbance state. Evidence presented concerning substrate conditions suggests that the channel has not returned to its pre-disturbance state.

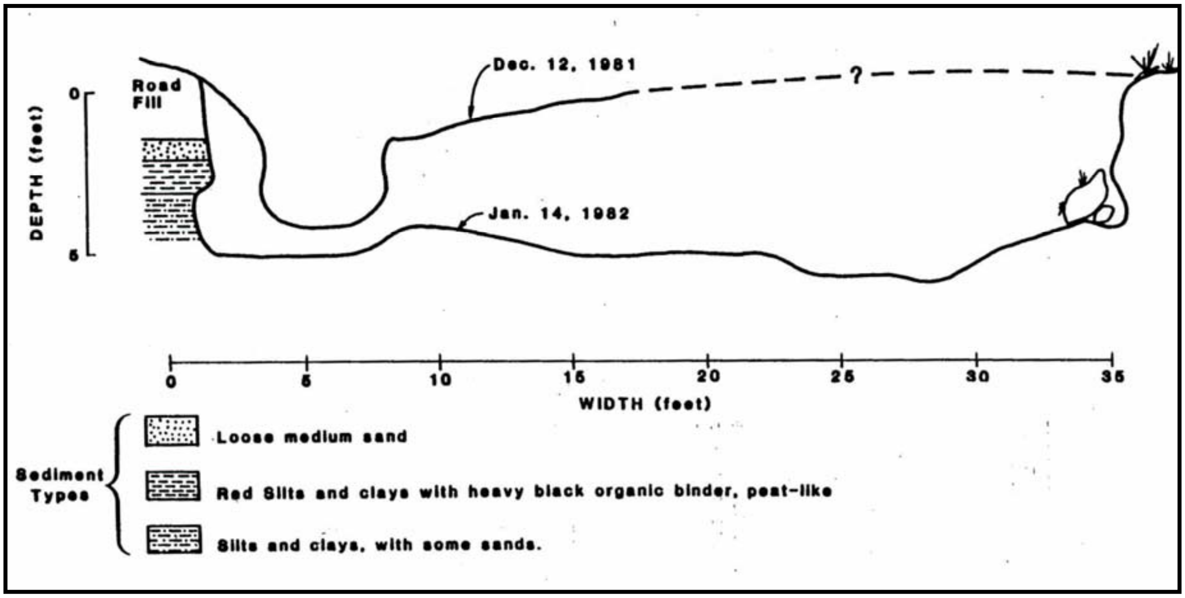

Figure 3-1: Channel Incision, Freedom Blvd. Creek, near Aptos High School. Most activity associated with event of January 4-5, 1982, although three other major storms occurred in the period between observations. Traced from field sketches made with a measuring tape.
Source: Hecht and Woyshner, 1984, p. E-17, Figure 5.

The fate of channel and bank sediments transported from the location of the cross-section is unknown. However, a reasonable hypothesis is that floodwaters entrained the material until they reached broader floodplain terraces of lower Valencia Creek where they deposited the sediment as "overbank deposits" and channel deposits. Some portion of the entrained material no doubt remained in suspension until floodwaters reached Monterey Bay. The depth of fine sediment in bank and channel deposits observed today in lower Valencia Creek, as well as particle size distributions measured by SH&G, are lines of evidence supporting this hypothesis. Fine sediment accumulations in lower Valencia Creek exceed Basin Plan narrative water quality objectives, since they are the cause of impairment of beneficial uses for aquatic life, including steelhead.

4. SOURCE ANALYSIS

This source analysis is based primarily on the *Final Report of the Geomorphology & Sediment Source Assessment Technical Memorandum* that SH&G (2003) prepared under contract to the Coastal Watershed Council. The California State Coastal Conservancy and the California Department of Fish and Game funded the work. SH&G's approach was to identify "the most significant sources of sediment, obtaining as much information as possible about the physical setting of the landscape that might infer a certain rate of erosion, and applying published erosion rates from other watersheds that exhibit similar patterns of erosion," (2003, p. 16). The four most significant sources of sediment in the watershed include: mass wasting, bank erosion, roads, and other hillslope landuses.

4.1. Mass Wasting

Approach and Methods

Landslides triggered by seismic activity, climatic conditions, and human disturbance contribute a tremendous quantity of material principally in the steep headwater portions of the Aptos Creek Watershed. Weber and Nolan conducted field mapping of landslides following the 1989 Loma Prieta earthquake in the Forest of Nisene Marks State Park. In the field they found no large, deep-seated (rotational-type) landslides triggered by the 1989 earthquake, and from limited historic data, no suggestion that such slides occurred in the 1906 earthquake. Instead the vast majority of slides triggered by the earthquake were relatively shallow debris and rock avalanches, slides and falls, most commonly occurring on steep slopes like the V-shaped inner gorge of Aptos Creek (Weber and Nolan, 1989, pp. 13, 14).

In spite of the potentially profound effects of seismically triggered slope failures, they must be viewed in a broader context, which spans decades of time and witnesses enormous variability in climatic conditions. Weber and Nolan state that the number of 'recent' landslides (last several decades) mapped in their study exceeds the number of landslides formed as a result of the Loma Prieta earthquake, and apparently also the 1906 earthquake. The landslides formed in the 83-year period between major earthquakes include at least one very large, deep-seated (rotational-type) landslide triggered by the heavy rains of the 1982-83 winter. "This observation suggest that the primary mechanism driving slope evolution in the Forest of Nisene Marks State Park is not seismic shaking, but climatic conditions (precipitation)," (Weber and Nolan, 1992, p. 369).

The landslide maps prepared by Weber and Nolan provide a level of detail previously unavailable for the portion of the watershed in the State Park (1989, p. 12). They include the location and extent of each landslide, the type of landslide, and an estimate of its age. SH&G digitized these maps at two levels of analysis: one level covered the entire State Park study area and included only slides estimated to have occurred in the last 50 years; the second level, limited to the Bridge Creek subwatershed, included all of the landslide features mapped by Nolan and Weber, including old slides that occurred 50 to 5,000 years before present (SH&G, p. 18). The finer scale analysis used in Bridge Creek allowed SH&G to develop a complete data set for one subwatershed, and it reveals the extent to which the overall landform of these upper watersheds are affected by mass wasting (see Figure 6, Appendix D).

To estimate the volume of sediment mobilized and delivered to streams by the process of mass wasting, SH&G assumed a depth of ten feet for each landslide feature. They based this on observations by Nolan and Weber that most recent slides were of the shallow, translational type, rather than deep rotational type.

SH&G calculated the volume of each recent (occurred in the past 50 years) slide, multiplying the surface area from the maps by the average 10-foot depth.

"The total mass wasting sediment volume for each subwatershed that occurred within the Park boundary was normalized by the corresponding subwatershed's area and a weighted average for the mapped areas was calculated." (SH&G, 2002a, p. 20). SH&G then performed the following manipulations of the data to extend their estimates of the amount of sediment generated by mass wasting to portions of the watershed outside Nolan and Weber's study area.

1) Given information on landslide age, SH&G calculated an annual erosion rate for the two age classes of landslides (10 and 50 years old), by dividing the volume of active slide features by 10 years and the volume of recent slide features by 50 years. This gave results in volume/year.
2) From Weber and Nolan's work they knew that the highest landslide rates in the mapped area were associated with instability along the fold axis of the Glenwood Syncline (Figure 2, Appendix D), which runs through subwatersheds 3 and 4 (Figure 1-1). The syncline also goes through subwatersheds 6 and 7 in upper Valencia Creek, so SH&G extrapolated the landslide volumes to these unmapped areas, normalizing for watershed area. This gave results in volume/area/year.
3) SH&G assumed that the remaining non-urbanized portions of the unmapped Valencia, Mangels and Trout Creek subwatersheds had similar landslide rates as the mapped areas outside the influence of the Glenwood Syncline. So, correcting for subwatershed area, they applied the rates from these similar areas outside the Park boundaries and totaled the volumes. In the urbanized subwatersheds (17, 18, 21, 23), they assumed no significant mass wasting occurs due to low slopes and urbanization (SH&G, 2003, p. 21).
4) Using a density of 123.5 lb/ft^3 derived from the literature, sediment volumes were converted to mass, yielding mass/area/year.
5) Finally, SH&G assumed that most landslide masses terminate at a stream channel, but much of the material remains on the hillslope and is eventually stabilized by vegetation. They therefore assigned a relatively low delivery efficiency of 20 percent for this sediment source, i.e., they assumed only 20 percent of the material mobilized by a landslide makes its way to the creek. (Ibid., p. 26).

Findings

The results presented in Table 4-4 reveal erosion rates ranging from 1,605 $tons/mi^2/yr$ in Mangels Gulch to 7996 $tons/mi^2/yr$ in Aptos Creek. Absolute yields range from 385 tons/yr in the smallest watershed with the lowest landslide rate, Mangels Gulch, to approximately 18,551 tons/yr in Aptos Creek. Valencia Creek, excluding the contribution from Trout Gulch, has an erosion rate less than half that of Aptos Creek. Mass wasting is the largest component of the watershed's sediment load (26,756 tons/yr).

SH&G was "reasonably confident" of their results derived through this approach, noting that the direction of any error was unknown. That error would be associated with the extrapolation of high quality landslide data from the State Park to areas outside the Park. (2003, p. 44).

4.2. Bank Erosion

Approach and Methods

SH&G conducted field measurements of bank erosion to form a basis for watershed-wide estimates of sediment volumes from this source. They surveyed a portion of each stream reach, recording bank erosion feature dimensions and location along the reach. From this information, they estimated the total square feet of bank erosion for each mile of surveyed reach (SH&G, 2003, p. 21). This square feet/mile figure was then applied to unsurveyed sections of the reach, assuming that the rates would be the same within a reach. Regional Board staff also conducted several reconnaissances and sampling runs on streams in the Aptos Creek Watershed between 2000 and 2004.

Going from an area/distance term to an erosion rate term, expressed as volume or mass/stream length/year, required SH&G to make additional assumptions about the depth and age of the erosion sites they observed. Since many of the erosion sites consisted of shallow composite failures due to bank undercutting, SH&G assumed an average depth of two feet. They also assumed an average age of 10 years for observed sites, since older sites would most likely be revegetated and not detectable. These assumptions lead to a resulting retreat rate is 0.2 ft/yr. Applying the retreat rate (ft/yr) to the area of erosion per mile of stream (ft^2/mi) they calculated the bank erosion rate for each subwatershed (ft^3/mi/yr). A density of 87.9 lb/ft^3 was used to translate this to *mass* per mile per year (lb/mi/yr). This density, taken from the literature, assumes the loosely consolidated silty sands comprising the banks throughout most of the watershed are less dense than landslide sediments (Ibid., p. 23). The delivery efficiency for bank erosion is 100 percent, since all bank material enters the stream.

Findings

SH&G determined Trout Gulch to have the highest rate of bank erosion in the watershed (327 tons/mi/yr), while Aptos Creek had the lowest (70 tons/mi/yr), (Table 4-4). However, with many more miles of stream channel, and the second highest bank erosion rate, Valencia Creek's banks contribute more than twice the amount of sediment of any other stream's banks. The total annual load from this source was estimated to be 8,184 tons/yr.

During reconnaissance, staff found bank disturbance commonly associated with residences and other developed uses of the riparian areas in the watershed. This disturbance, including vegetation clearing, dumping of dirt and debris, concentrated site drainage, footpaths, and a variety of efforts at bank protection, was often observed to directly result in erosion and sedimentation into the channel.

Bank erosion is also accelerated by the effects of urbanization outside of the riparian zone, as discussed previously in Section 3.4. Furthermore, large magnitude events such as the 1982 floods, in combination with historical changes to channel conditions (removal of wood from turn of century logging and settlement) accelerate bank erosion. Unfortunately, the limited data available on bank erosion does not permit staff to quantify the variable contributions of these different sources to the overall sediment load.

SH&G has reasonable confidence in their overall load estimate, but indicate that it may be a slight underestimation, because lower tributaries, which they did not emphasize in their survey, "may prove to be a source of a significant quantity of sediment since they would be directly impacted by increases in impervious surfaces that result in gully formation and channel incision," (SH&G, 2003, p. 44). Hecht and Woyshner's 1984 study in the lower watershed documents evidence of channel incision and increased flows.

SH&G further conclude, that "what is missing from our sediment budget analysis is an estimate of the amount of sediment that has historically been delivered to the channel and is in the process of being reworked and remobilized. Fine sediment deposits stored in the channel and in the floodplain, potentially due to turn of the century logging, may be remobilized under most flow conditions, due to the sandy nature of the deposits, and result in higher sediment yields than would be expected based on our estimate of erosion from hillslopes and banks" (Ibid, p. 35).

4.3. Roads

Introduction

Uncontrolled storm flow along roads, cutbanks or ditches may cause gully erosion on adjacent hillslopes and even affect the roadbed integrity, potentially resulting in failure and the delivery of large volumes of sediment to the stream (PWA, 2002, p. 9). A survey of 40 miles of county roads in the nearby San Lorenzo River watershed concluded that most future erosion and sediment delivery is expected to come from: 1) road fillslope failure (landslide), 2) erosion at or associated with crossings, 3) road surface and ditch erosion, and 4) gully erosion below ditch relief culvert outlets (Ibid., p. 5). The survey of San Lorenzo River roads found 124,114 cubic yards of future sediment delivery would come from roads (Ibid., p. 7). However, the time period over which this would occur is not specified in the report.

Roads that drain directly to streams and deliver runoff and fine sediment from cutbanks, ditches and/or road surfaces to the stream channel are "hydrologically connected." These roads are a potentially important source of chronic fine sediment. The San Lorenzo River County roads study found that 28.3 miles of the 40 miles surveyed were hydrologically connected. That study estimates that over 7,490 cubic yards of sediment will be delivered to stream channels over a ten-year period (approximately 31 tons/mi/year)[2] from these paved, hydrologically connected roads (Ibid., p. 9). Combining this chronic source with the other future sources, it is apparent that roads play a significant role in stream sedimentation.

Approach and Methods

While roads in the nearby Aptos Creek Watershed would likely have similar effects, no comparable assessment has been conducted to quantify their contribution to the total sediment load. Therefore, SH&G applied sediment yield estimates from a California Department of Forestry and Fire Protection (CDF) study of the East Branch of Soquel Creek to GIS and field-derived totals of road lengths. This was supplemented by Regional Board staff's analysis of Timber Harvest Plan roads in Trout Creek and Valencia Creek subwatersheds. (Timber harvesting has not occurred in other subwatersheds in recent history).

SH&G created a GIS roads layer from Santa Cruz County GIS data and from the Coastal Watershed Council's layer of unpaved roads in the State Park. Road data depicting residential and logging roads are not included in either of these data sources, though the County's data identifies paved versus unpaved. SH&G differentiated between roads near streams and roads distant from streams, since those near streams would likely contribute more sediment than those at some distance. Inner gorge roads were defined as those occurring within 50 feet of a first order stream, or, 100 feet of a second or third order stream, or 150 feet of a fourth order or greater stream. Roads farther than 150 feet from streams were defined as hillslope roads (SH&G, 2003, p. 24, 25).

SH&G derived road lengths on a subwatershed basis and placed them into the four categories of inner gorge paved and unpaved, and hillslope paved and unpaved (Table 4-1). Then they applied the erosion rates from the CDF study and an assumed density to get sediment yield in tons/mile/year.

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[2] Based on 40 total miles surveyed, a ten-year period, and an assumed density of 123.5 lbs/ft3.

Table 4-1 Sediment source yield estimates for roads in the Aptos Creek Watershed

Sediment Sources	Sediment Yield from CDF Study	Sediment Yield assuming soil density is 123.5 lbs/ft^3
Paved Inner Gorge Roads	46.8 yd^3/mi/yr	78 tons/mi/yr
Dirt Inner Gorge Roads	360 yd^3/mi/yr	600 tons/mi/yr
Paved Hillslope Roads	46.8 yd^3/mi/yr	78 tons/mi/yr
Dirt Hillslope Roads	360 yd^3/mi/yr	600 tons/mi/yr

Source: SH&G, 2003, p. 25.

Regional Board staff expanded the SH&G analysis to include roads in Timber Harvest Plans (THPs). Staff determined the number of harvested acres in THPs completed from 1992 to 2001 in the Valencia Creek and Trout Creek subwatersheds. As part of each THP submittal, proposed harvest acres and sections (from the Public Land Survey System) are identified. From these plans, staff located each harvest areas in a subwatershed. To generate miles of THP roads and skid trails, staff relied on a previous analysis of THPs throughout Santa Cruz County (CCRWQCB, 2002).

In that analysis, staff examined over 100 THPs to generate approximate ratios of road length to THP acreage. Staff recorded THP number, section(s), and harvest acres for each THP and entered these into a database. Some THPs did not specify how much of the total THP acreage occurred on each section, when THPs were located on multiple sections. When this occurred, the acreage was divided up evenly between each section. These data were joined to the Public Land Survey System (section level) GIS layer so that values for total harvest acres per section could be located geographically within the subwatersheds. Since section boundaries do not conform to watershed boundaries, harvest acres were apportioned to each subwatershed by using a ratio of the area of the section that was located within each subwatershed to the total acreage of the section. Acreages were converted to square miles using a conversion factor of 640 acres/mi^2.

Lengths of roads and skid trails were measured from maps included in the THP submittal. The maps varied greatly in quality and level of detail and only 73 of the 100 THPs reviewed were used to record lengths of road and trails. This analysis allowed staff to establish an *average length/acre* value for seasonal and temporary roads and skid trails associated with the THPs.

Staff found a distinct break between THPs below 150 acres, and THPs greater than or equal to 150 acres, in the average road and trail length per acre (Table 4-2). The value used to calculate THP road and trail lengths was increased by ten percent as a margin of safety (MOS) to account for the low quality of, and lack of detail on, some of the maps.

Table 4-2 Timber Harvest Plan road and trails length per acre

Logged Acreage	Average Length of Roads & Skid Trails (feet/acre)	Average Length of Roads & Skid Trails + 10% MOS (feet/acre)
<150 ac.	186	204
>=150 ac.	111	122

Source: CCRWQCB, 2002.

Because THP roads and trails close to streams would be expected to have higher sediment delivery efficiencies than those at some distance from streams, staff had to distinguish between the two. Since the level of detail in the analysis did not permit actual measurement of the location of roads relative to streams, staff made an assumption about the portion of THP roads and trails near streams. The ratio of inner gorge to hillslope THP roads (inner gorge – 16%, hillslope – 84%) was derived using the SH&G digitized data for the Zayante Area Sediment Study (2001). That study evaluated a large number of roads in the San Lorenzo River Watershed and identified this ratio. The ratio was applied consistently across each subwatershed to estimate the total length of inner gorge and hillslope THP roads within each subwatershed (Table 4-3). The streamside and upland THP road totals for Valencia and Trout Creek subwatersheds were added to the existing totals for unpaved roads developed from SH&G's GIS. The erosion rate per mile of road is assumed to be 600 tons/mi/yr as with other unpaved roads in this source analysis.

The sediment delivery ratios for hillslope roads was assumed to be 42 percent, based on the average delivery efficiency of sources studied in the CDF study in Soquel Creek (Cafferata and Poole, 1993, p. 36). For inner gorge roads it was assumed to be 100 percent. The assumed density used to calculate mass of sediment, was 123.5 lbs/ft3.

Table 4-3 Valencia and Trout Creek subwatershed THP acres and associated road lengths four ten-year period 1992 to 2001

	Acreages			**Length of Roads and Skid Trails (feet)**			**Upland Roads (84% of total)**		**Streamside Roads (16% of total)**	
	Total Harvested	Acres in Small THPs (<150 ac)	Acres in Large THPs (>=150 ac)	Small THPs (Multiplier = 204 ft/ac)	Large THPs (Multiplier = 122 ft/ac)	Total	(feet)	(miles)	(feet)	(miles)
Valencia	**944.7**	233.7	711	47,675	86,742	134,417	112,910	**21.4**	21,507	**4.1**
Trout	**96**	96	0	19,584	0	19,584	16,451	**3.1**	3,133	**0.6**

Findings

Inner gorge dirt and hillslope paved roads in Valencia Creek deliver almost 5,000 tons/yr of sediment to the stream according to this analysis (Table 4-4). Hillslope dirt roads deliver another 5,393 tons/yr contributing to almost 11,000 tons/yr of combined sediment from road erosion in this one subwatershed. Other subwatersheds have far fewer roads and consequently far lower sediment loads.

SH&G suggest that given the short timeframe of the CDF study, it is unlikely that their estimated erosion rates (78 and 600 tons/mi/yr for paved and dirt roads, respectively) capture the low probability, high magnitude storm events that cause failure of road fill prisms and culverts. If this is so, the rates are underestimating the contribution from roads (2003, p. 44).

4.4. Urban and Rural Lands

The source category urban and rural lands accounts for all sources from hillslopes except for roads and mass wasting. Rilling, gullying, overland flow and sheetwash are dominant processes of erosion on hillslopes. Additionally, temporarily disturbed lands and bare soils contribute to this source.

Approach and Methods

CDF estimated rates of erosion and sedimentation from urban and rural land in their study of the East Branch of Soquel Creek. Their estimates included mass wasting, which this source analysis has derived through other means (Section 4.1). This source analysis relies on the rates developed by CDF with corrections for the mass wasting component and for density.

CDF reports a sedimentation rate of 2.42 yd^3/ac/yr for non-forest lands stating that this rate is based on average sedimentation measured in Loch Lomond Reservoir and a delivery ratio of 0.4 (actually 0.42 — the assessment average) (Cafferata and Poole, 1993, p. 36). Loch Lomond Reservoir is located in the Newel Creek watershed, a tributary to the San Lorenzo River.

Conversions for Units and Density
To convert this rate from yd^3/ac/yr to tons/mi^2/yr, the following conversions were applied:

$$2.42\ yd^3 \times 27\ ft^3/yd^3 = 65.34\ ft^3$$

Using a density of 123.5 lb/ft^3 (from Holtz and Kovac, 1981,assuming moderately consolidated silty sand):

$$65.34\ ft^3 \times 123.5\ lb/ft^3 = 8{,}069.49\ lb \times 1\ ton/2{,}000\ lb = 4.035\ tons$$

So, $2.42\ yd^3/ac/yr = 4.035\ tons/ac/yr$

Then, converting from acres to square miles:

$$4.035\ tons/ac/yr \times 640\ ac/mi^2 = 2{,}582.4\ tons/mi^2/yr$$

Since, as CDF indicated, this sedimentation rate is only the fraction delivered, we can back-calculate the total erosion rate as follows:

$$2{,}582.4\ tons/mi^2/yr = 0.42\ (\text{erosion rate})\ \text{or,}$$
$$\text{erosion rate} = 2{,}582.4\ tons/mi^2/yr \div 0.42$$
$$\text{erosion rate} = 6{,}149\ tons/mi^2/yr$$

Correction for Mass Wasting
SH&G assumed that only 25 percent of eroded sediment from this source is from non-mass wasting sources. Thus, the CDF reported value could be converted to the erosion rate for Aptos Creek Watershed as follows:

$$6{,}149\ tons/mi^2/yr \times 0.25 = 1{,}537\ tons/mi^2/yr$$

SH&G derived totals for subwatershed area from their GIS for Aptos Creek Watershed and applied to these the erosion rate and a delivery efficiency of 42% to calculate annual sediment load from urban and rural lands. They made one correction to account for urbanization and impervious surface impacts in the Mangels, Trout, and Valencia Creek subwatersheds: SH&G multiplied the erosion rate in these subwatersheds by a factor of 1.24 (SH&G, 2003, p. 25).

Findings

The sediment yield from the urban and rural lands source category is greater than that from other categories in most subwatersheds (Table 4-4). Only mass wasting in Aptos Creek and bank erosion in Trout Gulch produce more sediment than urban and rural lands, according to these estimates.

This category is very broad and sources are distributed throughout the landscape making them challenging to accurately quantify without comprehensive, long-term studies of actual conditions. While the CDF study is the best information available on this source category, SH&G and Regional Board staff lack confidence in these resulting load estimates derived from that study's erosion rates.

Table 4-4 Estimated sediment yields from erosion sources by major subwatershed in Aptos Creek Watershed.

	Sub-Watershed	Feature Length (miles)	Erosion Rate (tons/mi/yr)	Delivery Efficiency	Sediment Delivery Rate to Streams (tons/mi/yr)	Sediment Yield (tons/yr)	Totals by Erosion Type (tons/yr)	Total Sediment Yield (tons/yr)
Inner Gorge Paved Roads	Aptos Creek	3.4	78	100%	78	265	**1,287**	**69,623**
	Mangels Gulch	2.0	78	100%	78	156		
	Trout Gulch	1.8	78	100%	78	140		
	Valencia Creek	9.3	78	100%	78	725		
Inner Gorge Dirt Roads	Aptos Creek	1.6	600	100%	600	960	**3,840**	
	Mangels Gulch	0.1	600	100%	600	60		
	Trout Gulch	0.6	600	100%	600	360		
	Valencia Creek	4.1	600	100%	600	2,460		
Hillslope Paved Roads	Aptos Creek	23.6	78	42%	33	773	**4,049**	
	Mangels Gulch	13.8	78	42%	33	452		
	Trout Gulch	14.1	78	42%	33	462		
	Valencia Creek	72.1	78	42%	33	2,362		
Hillslope Dirt Roads	Aptos Creek	6.0	600	42%	252	1,512	**7,686**	
	Mangels Gulch	None Mapped						
	Trout Gulch	3.1	600	42%	252	781		
	Valencia Creek	21.4	600	42%	252	5,393		
Bank Erosion	Aptos Creek	24.7	70	100%	70	1,729	**8,184**	
	Mangels Gulch	2.1	170	100%	170	357		
	Trout Gulch	6.0	327	100%	327	1,962		
	Valencia Creek	21.1	196	100%	196	4,136		
	Sub-Watershed	**Feature Area (mi^2)**	**Erosion Rate ($tons/mi^2/yr$)**	**Delivery Efficiency**	**Sediment Delivery Rate to Streams ($tons/mi^2/yr$)**	**Sediment Yield (tons/yr)**		
Mass Wasting	Aptos Creek	11.6	7,996	20%	1,599	18,551	**26,756**	
	Mangels Gulch	1.2	1,605	20%	321	385		
	Trout Gulch	2.3	2,316	20%	463	1,065		
	Valencia Creek	9.4	3,593	20%	719	6,755		
Urban and Rural Lands	Aptos Creek	11.6	1,537	42%	646	7,488	**17,821**	
	Mangels Gulch	1.2	1,906	42%	800	961		
	Trout Gulch	2.3	1,906	42%	800	1,841		
	Valencia Creek	9.4	1,906	42%	800	7,531		

Source: modified from SH&G, 2003, Table 4.

4.5. Conclusions from Source Analysis

General Validity of Loading Estimates

The source analysis generated overall estimates of loading entering the streams ("input") of the Aptos Creek Watershed. The estimate of the "output" term in the sediment budget developed by SH&G from their sheer stress and rating curve analysis (Section 3.3) provides a convenient check on the loading estimates from the source analysis. SH&G quantified the output at 25,694 tons/yr of sediment transported through the Aptos Creek tributary. Compare this to the 31,278 tons/yr from the various sources entering this same tributary and it is evident that the estimates are within reasonable range of each other. SH&G states: "Considering that a portion of the sediment eroded from the watershed is coarser material that may be stored in gravel and cobble bars and a portion is stored behind the extensive logjams that occur in the upper watershed, we feel these numbers correspond fairly well." (2003, p. 39).

Considering the Source

The relative importance of sediment sources is immediately evident when reviewing existing loads grouped by subwatershed (Table 4-5). Valencia Creek has high bank erosion and high road erosion while Aptos Creek tributary receives its highest loads from mass wasting. The loads reflect the fact that the rate of bank erosion in Valencia Creek is approximately three times greater than Aptos. The rate in Trout is almost five times greater than Aptos (Table 4-4). The source analysis included no assessment or quantification of overbank deposits in lower Valencia Creek. Reconnaissance of the area as well as anecdotal information on the effects of 1982 floods suggest that this may continue to be a significant source of sediment, principally through channel incision and bank erosion. SH&G offers this summary of the source analysis:

> "The important difference between conditions in Aptos and conditions in Valencia appears to be the source of the sediment and the capacity of the system to handle that sediment. Sources in Aptos primarily are derived from landslide material. In the case of a landslide, sediment is delivered episodically. Historic fisheries data suggest that Aptos is periodically inundated by large amounts of sediment that have devastated the fishery. Fortunately the system has recovered as subsequent storms flush out these sediments. In the absence of chronic inputs of fine material, the system is resilient and can recover. Valencia appears to experience the same episodic events, but unlike Aptos, has been unable to recover due to a combination of factors including geologic conditions, extensive fine-grained overbank deposits, and chronic fine sediment inputs from sources such as bank erosion or headcutting of first order tributaries" (2003, p. 39).

Table 4-5 Estimated sediment loading from four sources in the Aptos Creek Watershed

	Existing Load (tons/yr)							
TRIBUTARY	**APTOS**	**%**	**MANGELS**	**%**	**TROUT**	**%**	**VALENCIA**	**%**
Roads	3,510	11	668	28	1,744	26	10,940	37
Bank Erosion	1,729	6	357	15	1,962	30	4,136	14
Mass Wasting	18,551	59	385	16	1,065	16	6,755	23
Urban/Rural Lands	7,488	24	961	41	1,841	28	7,531	26
	31,278		**2,371**		**6,612**		**29,362**	

Hydromodification Summary

While not specifically a source of sediment, it is clear from this analysis that hydromodification of the lower watershed has a pronounced effect on the fate and transport of sediment from all source categories. The greater extent of hydromodification in the Valencia Creek subwatershed may explain vastly different substrate conditions there from those in Aptos Creek tributary. We believe that, despite high estimated sediment yields in Aptos Creek, episodic delivery of material mostly from landslides and a *stable hydrology* allow for adequate flushing and sorting of the delivered material to maintain aquatic habitat.

The significance of this is that loads alone are not causing impairment of beneficial uses, and by extension, reducing loads alone will not restore beneficial uses. As stated previously, the assimilative capacity of the waterbodies could be increased through better management of stormwater flows and other efforts to reduce the effects of hydromodification throughout the developed portions of the watershed.

Anthropogenic Loading

SH&G estimated percentages of the existing load that could be accounted for by human activities based on their knowledge of land uses occurring in the subwatersheds and on "an educated estimate of the percent of the total yield that is expected to be caused by human impacts, as opposed to naturally occurring erosion processes" (2003, p. 38). For example, sediment delivered to the channel from roads was assumed to be entirely anthropogenic, whereas other source categories were proportioned according to land use impacts observed in the watershed (Table 4-6). Because much of the Aptos Creek subwatershed is protected by the State Park, anthropogenic proportions there are the lowest (30 percent) of the subwatersheds. Based on these assumptions, the total anthropogenic portion of the sediment load on a subwatershed basis, ranges from 38% in the Aptos Creek subwatershed, to 81% in Valencia Creek subwatershed.

Table 4-6 Estimates of anthropogenic portion of existing loads in Aptos Creek Watershed

TRIBUTARY	Estimated Percent Anthropogenic[a]	Existing Load	Anthropogenic Load	Natural Load
APTOS			**(tons/yr)**	
Roads	100%	3,510	3,510	-
Bank Erosion	30%	1,729	519	1,210.3
Mass Wasting	30%	18,551	5,565	12,986
Urban/Rural Lands	30%	7,488	2,246	5,242
		31,278	**11,841**	**19,438**
			38%	**62%**
MANGELS				
Roads	100%	668	668	-
Bank Erosion	50%	357	179	179
Mass Wasting	50%	385	193	193
Urban/Rural Lands	50%	961	480	480
		2,371	**1,519**	**851**
			64%	**36%**
TROUT				
Roads	100%	1,744	1,744	-
Bank Erosion	70%	1,962	1,373	589
Mass Wasting	60%	1,065	639	426
Urban/Rural Lands	80%	1,841	1,473	368
		6,612	**5,229**	**1,383**
			79%	**21%**
VALENCIA				
Roads	100%	10,940	10,940	-
Bank Erosion	70%	4,136	2,895	1,241
Mass Wasting	60%	6,755	4,053	2,702
Urban/Rural Lands	80%	7,531	6,025	1,506
		29,362	**23,913**	**5,449**
			81%	**19%**

Notes: a) percentages estimated by SH&G, 2003, p. 38.

5. NUMERIC TARGETS

This section describes the numeric targets selected for Aptos Creek and tributaries. These targets are designed to protect the beneficial uses of the Aptos Creek Watershed. Since only narrative water quality objectives exist to protect beneficial uses, staff developed numeric targets that interpret or translate the narrative objectives.

5.1. General Discussion of Numeric Targets

Choosing appropriate numeric targets for sediment and relating these targets to sediment yield is difficult. The following quotes from the "Protocol for Developing Sediment TMDLs" (USEPA, 1999, p. 4-3).

> "The watershed processes that cause adverse sediment impacts are rarely simple. These processes often vary substantially over time and space, affect designated uses in more than one way (e.g., fish spawning and rearing life stages), and are frequently difficult to relate to specific sediment sources. *It is often appropriate to view sediment TMDLs as an iterative approach in which assessment tools, planning decisions, and sediment management actions are each evaluated over time to ensure that they are reasonably accurate and successful in addressing sediment concerns." (emphasis added)*

In light of these challenges, the numeric targets selected to indicate attainment of this sediment TMDL will be further evaluated through implementation and monitoring and be revised as necessary. Other parameters (e.g. large wood, percent impervious cover, total area of spawning gravels) could also be monitored in order to gain a better understanding of factors affecting the instream habitat. These other parameters may be used as targets in the future if it is determined that they are relevant measures of water quality improvement as it relates to sediment. The targets selected for this TMDL are adopted from Northern California coast sediment TMDLs and have already been approved for the Morro Bay and San Lorenzo River Sediment TMDLs in the Central Coast Region.

5.2. Description of Numeric Targets

Representative stream reaches will be selected to represent attainment as part of the monitoring strategy. Numeric target monitoring will be performed triennially during low flow conditions (after spring rains have ceased and prior to the start of fall/winter rains). The following parameters will be monitored within each reach, as appropriate.

Table 5-1 Numeric Targets for Aptos and Valencia Creeks

Parameter	Numeric Target[3]
Residual Pool Volume[4]	V* = Mean values $\leq$ 0.21 Max values $\leq$ 0.45
Median Diameter (D_{50}) of Sediment Particles in Spawning Gravels	D_{50} = Mean values $\geq$69 mm Minimum values $\geq$ 37 mm
Percent of Fine Fines (< 0.85 mm) in Spawning Gravels	Percent fine fines $\leq$ 21%
Percent of Coarse Fines (< 6.0 mm) in Spawning Gravels	Percent coarse fines $\leq$ 30%

Residual Pool Volume

Parameter: Residual Pool Volume (V*)

Numeric Target: $\leq$ 0.21 (mean) and $\leq$ 0.45 (max)

Since no data related to V* have been developed for the Aptos Creek Watershed or any comparable watersheds in the region, this value is taken from the Garcia River Sediment TMDL. The numeric target will be modified, if necessary, as V* data for the Aptos Creek Watershed become available.

Discussion: V* gives a direct measurement of the impact of sediment on pool volume. It is the ratio of the amount of pool volume filled in with fine, mobile sediment, and the total scour pool volume (Hilton and Lisle, 1993).

Overwintering habitat requirements include deeper pools, undercut banks, side channels, and especially large, unembedded rocks, which provide shelter for fish against the high flows of winter. In some years, such as 1982, extreme floods may make overwintering habitat the critical factor in steelhead production. In most years, however, if the pools have sufficient larger boulders or undercut banks to provide summer rearing habitat for yearling steelhead, then these elements are sufficient to protect them against winter flows.

Median Particle Size

Parameter: Median particle size diameter (D_{50}) in spawning gravels

Numeric Target: > 37 mm (minimum for a reach); > 69 mm (mean for a reach); with an approximately normal distribution of grain size.

[3] Target values are for sampling reach(es) within an individual waterbody.

[4] Residual Pool Volume refers to the portion of a pool in a stream that is available for fish to occupy. Pool habitat is the primary habitat for steelhead in summer. Overwintering habitat requirements include deeper pools, undercut banks, side channels, and especially large, unembedded rocks, which provide shelter for fish against the high flows of winter. V* gives a direct measurement of the impact of sediment on pool volume. It is the ratio of the amount of pool volume filled by fine, mobile sediment, to total pool volume. Qualifying pools are those having a gradient less than 5%, a minimum depth twice the riffle-crest depth, a fairly even spacing between tributaries, and are located on streams fifth order or smaller.

Discussion (adapted from Redwood Creek Sediment TMDL (USEPA, 1998): The D_{50} is the median value of the particle size distribution in a sample of spawning gravel. It is a measure of the central tendency of the whole sample, and thus is one of several indicators of how "fine" or "coarse" the sample is overall. Both amount and size of fine and coarse sediments can impact salmonid lifestages.

The D_{50} indicator is selected for Aptos and Valencia Creeks and their tributaries because it is easy to calculate based on results from pebble counts. In a study that evaluated the relationship between hillslope disturbance and various instream indicators, Knopp (1993) found a clear trend of decreasing particle sizes in the riffles with increasing hillslope disturbance. Moreover, Knopp found a statistically significant difference in average and minimum D_{50} values when comparing reaches in undisturbed and less disturbed watersheds with reaches in moderately and highly disturbed watersheds.

Therefore, the D_{50} levels identified in undisturbed and less disturbed locations are good candidates for numeric targets in this watershed. Knopp also found that the moderately disturbed reaches were not statistically different from the highly disturbed reaches. This indicates that D_{50} results may take upwards of 40 years before mitigation of current disturbance is positively reflected. The recommended numeric targets may require revision as more data are gathered within the watershed. By setting two numbers in the Redwood Creek Sediment TMDL (mean and minimum), USEPA recognized that the annual variability in this target.

Percent of Fine Fines in Spawning Gravels

Parameter: Percent fines < 0.85 mm in spawning gravels

Numeric Target: $\leq$ 21% by dry weight using McNeil Sampler.

This value is derived from published, peer-reviewed literature (Kondolf, 2000) since no data currently exists for this parameter within the Aptos Creek Watershed. Regional Board Staff determined this to be a reasonable initial numeric target for spawning areas in the watershed, since the impact to developing steelhead and salmon there should be similar to those in geographic locations where most studies have been undertaken. The value of 21 percent was derived using research values for the base percentage of fines (14 percent) and multiplying it by a factor (1/0.67) to account for fine sediment removal that occurs when redds (nesting gravels) are constructed. The value of 14 percent was used in the Garcia River Sediment TMDL (USEPA, 1998b, p. 16) and is also referenced by Kondolf (2000, p. 271). Kondolf suggests that survival rates would be around 50 percent where fines less than approximately 1 mm in size make up 14 percent of the total redd gravel. Redds with at least 50 percent emergence success would probably be considered as productive by most biologists (Ibid.)

The factor used to account for the fines removal during redd construction was taken from Kondolf (2000, p. 268). It was derived using linear regression for data collected from eleven sites. Kondolf found that there was a linear relationship between the percent < 1 mm in the undisturbed gravel, and the percent < 1 mm (represented by "y") in the redd gravel. The following equation represents this relationship:

Equation 1:
$y = 0.67\,x$
Where:
X = percent < 1 mm in the undisturbed gravel
Y = percent < 1 mm in the redd gravel

In order to go from a desired gravel condition to an initial gravel condition Equation 1 must be rearranged to:

Equation 2:
x = y/0.67

The Numeric Target in potential spawning gravels then, is:

21%=14/0.67

Discussion: "Once the eggs are laid and fertilized, the spawners cover the redds with material from upstream, including clean gravels and cobbles. The interstitial spaces between the particles allow for water to flow into the interior cavity where dissolved oxygen, needed by the growing embryos, is replenished. Similarly, the interstitial spaces allow water to flow out of the interior cavity carrying away metabolic wastes. However, fine particles either delivered to the stream or mobilized by storm flow can intrude into those interstitial spaces, blocking the flow of oxygen into the redd and the metabolic wastes out of it. The reduced permeability into and out of the redd results in a reduction in the rate of embryo survival. Research on this subject has concluded that as the percentage of fines increases as a proportion of the total bulk core sample, the survival to emergence (i.e., out of the gravel) decreases. Fines that impact embryo development are generally defined as particles that pass through a 0.85 mm sieve" (USEPA, 1998b, p. 16).

Percent of Coarse Fines in Spawning Gravels

Parameter: Percent fines < 6 mm in spawning gravels

Numeric Target: $\leq$30% by dry weight using a McNeil Sampler

Values characterizing the effect of coarser fine sediment on emergence appear in the literature and staff relied upon these to establish this numeric target. Values associated with 50% emergence average about 30% for sediment finer than both 3.35 mm and 6.35 mm (Kondolf, 2000, p. 271). Staff considers 30% to be a legitimate numeric target for the Aptos Creek Watershed, since the impact to developing steelhead and Coho salmon from fines there should be similar to those for geographic locations where most studies have been undertaken. The grain size of 6 mm was chosen because it falls between the values cited by Kondolf (3.35 mm and 6.35 mm) associated with the value of 30% used as the numeric target. No factor accounting for removal of coarser fines by fish during redd construction was applied to this value, as was done for the percent fines less than 0.85 mm because data are more variable than similar data for fines less than 0.85 mm.

Discussion: Sedimentation has been identified as one of the principal factors in determining the survival rate from deposition to hatching of eggs and the survival rate from hatching to emergence from the gravel (Shapovalov and Tact, 1954, p. 155). The coarser fines, > 0.85 mm and < 6.5 mm, can impede emergence of fry from the redd thereby reducing survival rates for fry.

"Steelhead and salmon require spawning sites with gravels (from ¼ in. to 3-1/2 in. diameter) having a minimum of fine material (sand and silt) mixed with them and with good flows of clean waters moving over and through them. Increases in fine materials from sedimentation, or cementing of the gravels with fine materials, restrict water and oxygen flow through the redd to the fertilized eggs. These restrictions reduce hatching success.

6. LINKAGE ANALYSIS

This linkage analysis examines the relationship between sediment loadings and numeric targets identified in previous sections. The linkages addressed are identified below.

This TARGET	is LINKED	to the LOADING to:
River Residual Pool Volume	←→	Aptos Creek and Valencia Creek
Median Gravel Diameter		
Percent *Fine* fines		
Percent *Coarse* fines		

Staff assumes that changes in the target parameters are linked to changes in sediment load, but that these linkages are generally indirect and highly variable. However, over the long term, reductions in sediment inputs to the stream are expected to result in reduced sedimentation in the channel and improvements in numeric target parameters. Improved linkage may be realized through evaluation of monitoring data collected to measure progress toward each target.

Knopp's (1983) study of northern California coastal streams demonstrated that sediment generated from upslope disturbance had a measurable effect on the structure of the aquatic environment (p.40). He identified a statistical link between watershed disturbance and several in-stream sediment indicators, including residual pool volume (V*) and median gravel diameter (D_{50}). This linkage is the basis for selecting the four stream substrate targets.

7. TOTAL MAXIMUM DAILY LOAD AND ALLOCATIONS

A stream's assimilative capacity for sediment, for the purposes of this discussion, is that group of attributes that accounts for the distribution, transport, and retention of sediment in a manner that generates and sustains fish habitat. The assimilative capacity for sediment in the Aptos Creek Watershed is different from stream to stream. This difference is best demonstrated by contrasting Aptos Creek, where most of the anthropogenic sediment load is assimilated to the extent that suitable fish habitat is common, with Valencia Creek, which possesses less suitable habitat with comparable loading. We would expect that reducing the sediment load by the same proportion in two creeks with different assimilative capacities would have different outcomes relative to habitat quantity and quality.

We therefore infer that reducing the Valencia Creek sediment load to natural levels may not in fact result in habitat conditions comparable to those of Aptos Creek. Such conditions may only be possible when the assimilative capacity of Valencia Creek is increased. Clearly there is more to the problem than loads. Altered watershed hydrology, reduced quantities of large wood, and bank disturbance (e.g., hardening with rip-rap) are implicated in reducing the assimilative capacity of the streams, so the appropriate strategy for restoring beneficial uses combines source reduction with efforts to affect these factors. The appropriate balance of source reduction and efforts to increase assimilative capacity is impossible to determine with existing information and without accurate forecasting of future disturbances (large events such as floods, earthquakes, landslides, and fires).

Lacking a methodology for quantifying changes in assimilative capacity, and required by statute (CWA, Section 303(d)) to identify allowable loads, staff has calculated loads (TMDLs) that we expect would produce conditions supportive of beneficial uses in streams of the Aptos Creek Watershed. The approach to establishing allowable loads is based on staff's judgment that these streams can assimilate a certain portion of load above background load while still meeting water quality objectives for settleable solids. We further assert that the Aptos Creek tributary is largely supporting beneficial uses and provides an example of a waterbody approaching the desired condition relative to sedimentation.

The quantitative results of this allocation scheme should not be assumed to explicitly represent sediment reductions expected by any one of the individual implementing parties. The expectation is that these allocations will be met through an adaptive management strategy that will adjust implementation actions based on tracking Best Management Practice implementation and progress and trends in numeric targets. This approach also recognizes that target attainment may result from a combination of load reduction and increased assimilative capacity.

7.1. Approach to Establishing Allowable Loads

The source analysis concludes that approximately 38 percent of the load in Aptos Creek tributary is anthropogenically derived. Since this tributary supports beneficial uses to a large extent, there is no compelling reason to seek the complete elimination of the anthropogenic portion of load. Apparently, the assimilative capacity of the tributary is adequate to absorb most of this excess sediment. Instead the existing load of the Aptos Creek tributary should be reduced by the percent controllable with conventional erosion control practices.

The following will demonstrate that the resulting allocation for this one tributary is approximately 29 percent above the estimated natural load. Staff has selected this percentage as the basis for allocations in the remaining tributaries. The allocations are then based on three factors: the percent of existing load that is controllable, the estimated natural load, and the condition of the Aptos Creek tributary, which approaches desired conditions relative to sedimentation.

Percent Controllable through Best Management Practices

Large reductions in erosion associated with each source category can be realized through the use of standard Best Management Practices (BMPs). For example, treatment of cut and fill slopes and road surfaces can achieve reductions that range from 32-47% for cut slopes, 50-99% for fill slopes, and 70-99% for road surfaces. Additionally, it has been demonstrated that up to 80% of Total Suspended Solids can be removed from run-off from new development (USEPA, 1993, p. 4-12), which is a land-use included in the "Urban and Rural Land" source category. Even chronic fine sediment from mass wasting can be controlled by the installation of drainage systems that reduce surface erosion. And channel and streambank erosion can be controlled by bank stabilization, healthy riparian corridor vegetation growing in reasonable stream setbacks, and through the use of riparian buffer easements.

Further discussion of available sediment reduction measures can be found in the Zayante Area Sediment Source Study (SH&G, 2001, pp. 39, 55, Table 4-4) and in the EPA's Guidance Specifying Management Measures for sources of Nonpoint Pollution in Coastal Waters, (USEPA, 1993). Percent controllable loads for each sediment source category were developed as part of the Zayante Area Sediment Source Study. The estimated reductions attainable through BMPs were reviewed and accepted by the San Lorenzo River Technical Advisory Committee, consisting of representatives of interested groups within the San Lorenzo Watershed. The discussion of the estimated reductions below is from the Zayante Study (SH&G, 2001, pp. 41-42):

Upland THP Roads and Skid Trails (50%): Reduction of sediment loads from THP roads and skid trails on hillslopes will largely depend upon cooperation with landowners, monitoring and maintenance of roads beyond the period required by CDF and additional expenditure. Sediment load reductions from existing roads could be tied to future timber harvest proposals. For these reasons, it was assumed that only a 50 percent reduction could be achieved.

Streamside THP roads and Skid Trails on steep slopes (50%): Streamside THP roads and skid trails on steep slopes trails typically occur within a geologically unstable area, reducing the potential effectiveness of treatments. For this reason in addition to the reasons cited above for Upland THP roads and skid trails, only a 50 percent reduction is assumed.

Upland Public and Private Roads (50%): Hillslope erosion control will largely depend upon the cooperation of multiple landowners for private roads and Santa Cruz County for public roads. This will be especially important to create systematically continuous drainage systems. Treatment of hillslope drainage should result in a beneficial reduction in mass wasting and concentration of flow in the steep streamside slopes. Although geologically more stable than steep streamside slopes, landownership is predominately private. For these reasons, a 50 percent reduction in supplies was assumed.

Public and Private Streamside Roads on Steep Slopes (50%): Streamside roads on steep slopes are largely publicly owned and assumed accessible. Private streamside roads on steep slopes may have limited accessibility depending upon landowner cooperation. Treatment success may be difficult due to unstable geologic setting and steep terrain. For these reasons, the controllable load has been set to 50 percent.

Urban and Rural Lands (30%): Urban and rural lands are a mix of public and private ownerships, thus limiting factors are funding resources and landowner (private or agency) cooperation. For these reasons a 30 percent reduction has been assumed.

Mass Wasting (Natural and Human Caused) (10%): Mass wasting in this sediment load allocation is the episodic and non-point source component. The "human caused" component results from excessive grading and/or poor drainage conditions on roads and development on hillslopes and in the steep streamside slopes. Direct treatment of landslides is usually difficult and expensive and in many cases requires access to private lands. However, proper treatment of surface drainage and erosion problems within the categories listed above should help reduce human caused mass wasting. The 10% reduction is assumed to be an ancillary benefit to treatment of surface erosion problems.

Channel/Bank Erosion (20%): Treatment of channel erosion problems is difficult due to lack of construction access and geologic instability. Bank erosion problems are often expensive to treat and are usually not undertaken unless valuable property or structures are at risk. In addition, installation of bank control structures may cause more bank erosion thereby undoing benefits. For these reasons, sediment reduction at channel erosion sites is assumed to be 20 percent.

Percent Controllable Load in Aptos Creek Tributary

Based on these estimates of attainable reductions, the existing load in the Aptos Creek tributary is estimated to be 20 percent controllable through application of conventional BMPs (Table 7-1). As stated previously, the existing load of the Aptos Creek tributary should be reduced by the percent controllable. So, the existing load minus 20 percent would be the allowable load, or, the TMDL. Note that this approach aggregates the controllable load to a subwatershed basis and blurs the contributions of each source category. This is done in part to simplify the calculations, but more importantly it introduces flexibility in how the load reductions are achieved and avoids the presumption that the “percent controllable” is a rigid number. For example, if more than 50 percent of road erosion was controlled, it could offset the failure to achieve the full 30 percent of reductions from urban and rural lands, and at the subwatershed level, 20 percent reduction could still be achieved.

Table 7-1 Estimated percent controllable load in the Aptos Creek tributary using conventional Best Management Practices.

	A	B	C	D
APTOS	**Existing Load**	**Percent Controllable**	**Controllable Load**	**Attainable Load**
		(Tons/yr)	**C=A*B**	**D=A–C**
Roads	3,510	50%	1,755	1,755
Bank Erosion	1,729	20%	346	1,383
Mass Wasting	18,551	10%	1,855	16,696
Urban/Rural Lands	7,488	30%	2,246	5,242
	31,278		**6,203**	**25,076**
			20%	***80%***

This allowable load of existing minus 20 percent is still greater than the natural load. In fact it is 29 percent greater than natural load. The 29 percent is derived as illustrated in the following table using a hypothetical existing load of 100 tons/yr (Table 7-2).

Table 7-2 Hypothetical calculation of percent of allowable load over natural load

Existing Load	**Percent Anthropogenic** (See Table 4-6)	**Percent Natural**	**Percent Controllable** (See Table 7.1)	**Allowable Load**	**Allowable Load is this % above Natural**
E	**0.38(E)**	**0.62(E)**	**0.2(E)**	**E – 0.2(E)**	$\frac{(E-0.2E) - 0.62(E)}{0.62(E)}$
100	38	62	20	100 – 20 = 80	$\frac{80 - 62}{62} = 29\%$

Staff has concluded that beneficial uses will be protected in Aptos Creek tributary when the existing load is reduced by 20 percent, which is equivalent to 29 percent over the estimated average natural load. The TMDL for other tributaries in the Aptos Creek Watershed is based on this approach to restoring beneficial uses in the Aptos Creek tributary: allowable loads in Mangels Gulch, Trout Creek, and Valencia Creek tributaries are set at 29 percent above natural loads.

While the Aptos Creek tributary loads can be reduced by 20 percent down to 80 percent of existing load using BMPs, the same is not true of the remaining tributaries with higher loads. These tributaries' existing loads can be reduced by 29 percent or 31 percent using BMPs (Table 7-3). This is because, compared to the Aptos Creek tributary, a greater proportion of loads in the remaining tributaries are from erosion categories that are more controllable (e.g., roads are 50 percent controllable, while mass wasting is only 10 percent controllable) (see Table 4-5 for existing load breakouts by erosion categories).

Table 7-3 Estimated percent controllable load in the remaining tributaries using conventional Best Management Practices.

	A	B	C	D
WATERBODY Erosion Category	**Existing Load**	**Percent Controllable**	**Controllable Load**	**Attainable Load**
			C=A*B	**D=A–C**
MANGELS	(Tons/yr)			
Roads	668	50%	334	334
Bank Erosion	357	20%	71	286
Mass Wasting	385	10%	39	347
Urban/Rural Lands	961	30%	288	672
	2,371		**732**	**1,639**
			31%	***69%***
TROUT				
Roads	1,744	50%	872	872
Bank Erosion	1,962	20%	392	1,570
Mass Wasting	1,065	10%	107	959
Urban/Rural Lands	1,841	30%	552	1,289
	6,612		**1,923**	**4,689**
			29%	***71%***
VALENCIA				
Roads	10,940	50%	5,470	5,470
Bank Erosion	4,136	20%	827	3,308
Mass Wasting	6,755	10%	675	6,079
Urban/Rural Lands	7,531	30%	2,259	5,272
	29,362		**9,232**	**20,130**
			31%	***69%***

7.2. TMDL Calculations and Allocations

TMDLs

The calculation of the Total Maximum Daily Load for tributaries to Aptos Creek, expressed here as tons per year, is based on allowing 29 percent above natural annual loads. The resulting TMDL for Aptos Creek, which is the sum of all tributaries, is 34,987 tons/yr (Table 7-4). The TMDL for Valencia Creek is the combined allowable load for the two tributaries Valencia Creek and Trout Gulch (1,784 + 7,029), or 8,813 tons/yr.

Table 7-4 Calculation of TMDLs for Aptos Creek Watershed in tons/year

TRIBUTARY	A	B	C	D	E	F		
	Existing Load	**Anthropogenic Load**	**Natural Load**	**Percent Controllable (aggregate)**	**Controllable Load (aggregate)**	**Attainable Load**	**Allowable Load (TMDL)**	**Percent Reduced from Existing**
	(Table 4-5)	(Table 4-6)		(Tables 7-1, 7-2)			29% over natural, or, 29%(C)+C	
		% X A	A - B	Avg. BMP effectiveness	A * D	A - E		
APTOS	**31,278**	**11,841** 38%	**19,438** 62%	**20%**	**6,203** 20%	**25,076** 80%	**25,076**	**20%**
MANGELS	**2,371**	**1,519** 64%	**851** 36%	**31%**	**732** 31%	**1,639** 69%	**1,098**	**54%**
TROUT GULCH	**6,612**	**5,229** 79%	**1,383** 21%	**29%**	**1,923** 29%	**4,689** 71%	**1,784**	**73%**
VALENCIA	**29,362**	**23,913** 81%	**5,449** 19%	**31%**	**9,232** 31%	**20,130** 69%	**7,029**	**76%**
						APTOS CREEK TMDL:	**34,987**	

Allocations

Table 7-5 presents the allocation of loading to source categories: roads, bank erosion, mass wasting, and urban and rural lands. Outside of Aptos Creek subwatershed roads are not allocated a load, since there is no natural loading from roads and 29 percent of natural in this case would be zero. Therefore load reductions are assigned to other categories within the subwatersheds to allow some of the existing contribution from roads to continue. This provides that the subwatershed total allocations, hence the TMDL, will be met.

Table 7-5 Load allocations to major sediment sources

	Tons/Year[1]			
	A	B	C	D
TRIBUTARY Sources	**Existing Load**	**Anthropogenic Load**	**Natural Load**	**LOAD ALLOCATION**
APTOS	(See Table 4-4)	(See Table 4-6)		(See Table 7-1 for Aptos Trib. Only)
Roads	3,510	3,510	-	1,755
Bank Erosion	1,729	519	1,210	1,383
Mass Wasting	18,551	5,565	12,986	16,696
Urban/Rural Lands	7,488	2,246	5,242	5,242
	31,278	**11,841**	**19,438**	**25,076**
		38%	***62%***	
MANGELS				Based on 29% above Natural Or, (D=(0.29* C) + C)
Roads	668	668	-	-
Bank Erosion	357	179	179	230
Mass Wasting	385	193	193	248
Urban/Rural Lands	961	480	480	620
	2,371	**1,519**	**851**	**1,098**
		64%	***36%***	
TROUT				
Roads	1,744	1,744	-	-
Bank Erosion	1,962	1,373	589	759
Mass Wasting	1,065	639	426	550
Urban/Rural Lands	1,841	1,473	368	475
	6,612	**5,229**	**1,383**	**1,784**
		79%	***21%***	
VALENCIA				
Roads	10,940	10,940	-	-
Bank Erosion	4,136	2,895	1,241	1,600
Mass Wasting	6,755	4,053	2,702	3,485
Urban/Rural Lands	7,531	6,025	1,506	1,943
	29,362	**23,913**	**5,449**	**7,029**
		81%	***19%***	

1) Rounded to nearest ton.

Wasteload Calculation

The following is the arithmetic expression of a total maximum daily load:

TMDL = ΣWLA + ΣLA + MOS

Where:

WLA	=	wasteload allocation, or the portion of the TMDL allocated to existing or future point sources
LA	=	load allocation, or the portion of the TMDL allocated to existing or future nonpoint sources and natural background; and
MOS	=	margin of safety, or an accounting of uncertainty about the relationship between pollutant loads and receiving water quality. The MOS can be provided implicitly through analytical assumptions or explicitly by reserving a portion of loading capacity.

Sediment from urban and rural sources is generated through erosion from unpaved areas and disturbed sites and can be carried into streams through surface runoff. While such stormwater discharges are diffuse and distributed in a manner similar to *nonpoint sources*, sediment contributions from urban and even rural runoff can be legally considered *point sources* and subject to permit under the Clean Water Act. The determination of whether a permit is required for stormwater discharges is based on how these discharges are conveyed to waterbodies. A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains) designed or used for collecting or conveying stormwater is known as a "MS4"—for Municipal Separate Storm Sewer System. Stormwater conveyed through a MS4 is subject to a permit [See Title 40, Code of Federal Regulations Section 122.26(b)(8)].

Smaller urbanized areas with MS4s, like portions of the Aptos Creek Watershed, are required to address water quality impacts related to stormwater runoff as part of the National Pollutant Discharge Elimination System (NPDES) and are subject to an NPDES Phase II Municipal Stormwater Permit. Pursuant to the permit, Santa Cruz County is required to develop and implement a Stormwater Management Program (SWMP) that addresses water quality related issues. The County has chosen to include the entire County within the permit boundaries to simplify jurisdictional issues in managing stormwater. However, programs listed in the SWMP were developed for, and will focus on, the urbanized areas of the County where the County actually maintains conveyances (Santa Cruz County and City of Capitola, 2004, pp. 2-7, 2-8).

As illustrated in the box above, the calculation of TMDLs requires segregation of point sources (*wasteload*) from nonpoint sources (*loads*). Staff has therefore identified a portion of the source category "Urban and Rural Lands" as a *wasteload* allocation, while all other sources are considered nonpoint source *load* allocations. The basis for identifying a portion of the Urban and Rural Lands source category as a wasteload was simply that much of it will be conveyed through the County's MS4, and is under the NPDES Phase II Municipal Stormwater Permit. The final allocation was based on the estimated anthropogenic portion of the total load from this category (Table 7-6).

We recognize that a portion of the load from Urban and Rural Lands will not be conveyed through the County's MS4. We also recognize that not all stormwater conveyed through the MS4 is of anthropogenic origin. Nevertheless, basing the wasteload allocation on the anthropogenic percentage avoids an arbitrary allocation that we would otherwise be forced to make without information on the actual portion of Urban and Rural Lands loading conveyed through the MS4.

Table 7-6 Calculation of wasteload portion of TMDL contributed by urban and rural lands

Tributary	Urban and Rural Lands Existing Load	Allowable Load	Anthropogenic Portion of Existing Load	Wasteload (Anthro % x Allowable load)	Load Allocation
	tons/yr			tons/yr	
Aptos Creek	7,488	5,242	30%	1,573	3,669
Mangels Gulch	961	620	50%	310	310
Trout Gulch	1,841	475	80%	380	95
Valencia Creek	7,531	1,943	80%	1,554	389
	17,821	**8,279**		**3,817**	**4,463**

Final TMDL

With the adjustments for waste load allocation, the final TMDLs for Aptos Creek and Valencia Creek are indicated in Table 7-7.

Table 7-7 Calculation of TMDL with explicit Waste Load Allocation (WLA) and Load Allocation (LA)

	Allowable load from all sources	=	WLA from Urban/Rural Land	+	LA
Aptos Creek	25,076	=	1,573	+	23,503
Mangels Gulch	1,098	=	310	+	789
Trout Gulch	1,784	=	95	+	1,689
Valencia Creek	7,029	=	389	+	6,640
APTOS CREEK TMDL (Sum of all tributaries)	**34,987**	**=**	**2,366**	**+**	**32,621**
VALENCIA CREEK TMDL (Sum of Trout and Valencia tributaries)	**8,813**	**=**	**484**	**+**	**8,329**

Margin of Safety

The margin of safety is a required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving water (CWA 303(d)(1)(C)). There are two methods for incorporating the margin of safety (USEPA, 1991):

1. Implicitly incorporate the margin of safety using conservative model assumptions to develop allocations.
2. Explicitly specify a portion of the total TMDL as the margin of safety and use the remainder for allocations.

For the Aptos Creek and Valencia Creek sediment TMDLs, an implicit margin of safety was incorporated through estimates of existing load that are considered to be likely underestimates of the actual load. This is apparent when one considers that the TMDL is the sum of allocations, which are based on a percentage of the estimated existing loads. For example, from the estimate of existing load we calculated the natural load as a percent of existing load (Table 4-6). So if the existing load is estimated to be relatively high, then the allocation, as a percentage of that existing load, will also be relatively high. Similarly, if existing loads are underestimated, the ultimate allocation will be lower and more conservative.

Staff is not able to calculate the magnitude of the underestimates but we are confident that they occur relative to sediment loading from roads, bank erosion, and overbank deposits. The basis for believing these sources were underestimated is discussed in the Source Analysis.

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